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Suzuki

(10) **Patent No.: US 9,257,817 B2**
(45) **Date of Patent: Feb. 9, 2016**

(54) **SPARK PLUG HAVING FUSION ZONE**

(75) Inventor: **Akira Suzuki**, Aichi (JP)

(73) Assignee: **NGK SPARK PLUG CO., LTD.**, Aichi (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 137 days.

(21) Appl. No.: **13/880,623**

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§ 371 (c)(1),
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(30) **Foreign Application Priority Data**

Nov. 17, 2010 (JP) 2010-256523

(51) **Int. Cl.**
H01T 13/20 (2006.01)
H01T 13/32 (2006.01)
H01T 21/02 (2006.01)

(52) **U.S. Cl.**
CPC ***H01T 13/20*** (2013.01); ***H01T 13/32*** (2013.01); ***H01T 21/02*** (2013.01)

(58) **Field of Classification Search**
CPC H01T 13/32; H01T 13/20; H01T 21/02
USPC 313/141, 144, 138, 118
See application file for complete search history.

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Primary Examiner — Anh Mai
Assistant Examiner — Glenn Zimmerman
(74) *Attorney, Agent, or Firm* — Sughrue Mion, PLLC

(57) **ABSTRACT**

A spark plug (**1**) includes a center electrode (**5**), an insulator (**2**), a metallic shell (**3**), a ground electrode (**27**), and a noble metal tip (**32**) provided on at least one object member of the center electrode and the ground electrode. One end surface of the noble metal tip is joined to the object member via a fusion zone (**35**). The fusion zone includes a first fusion zone (**351**) formed through radiation of a laser beam or the like to the boundary between the object member and the one end surface of the noble metal tip along a perimetrical direction of the noble metal tip, and a second fusion zone (**352**) formed through radiation of the laser beam or the like from the side from which the laser beam or the like has been radiated in forming the first fusion zone, and intersecting with the first fusion zone.

23 Claims, 27 Drawing Sheets

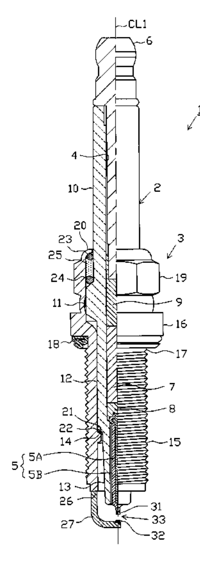

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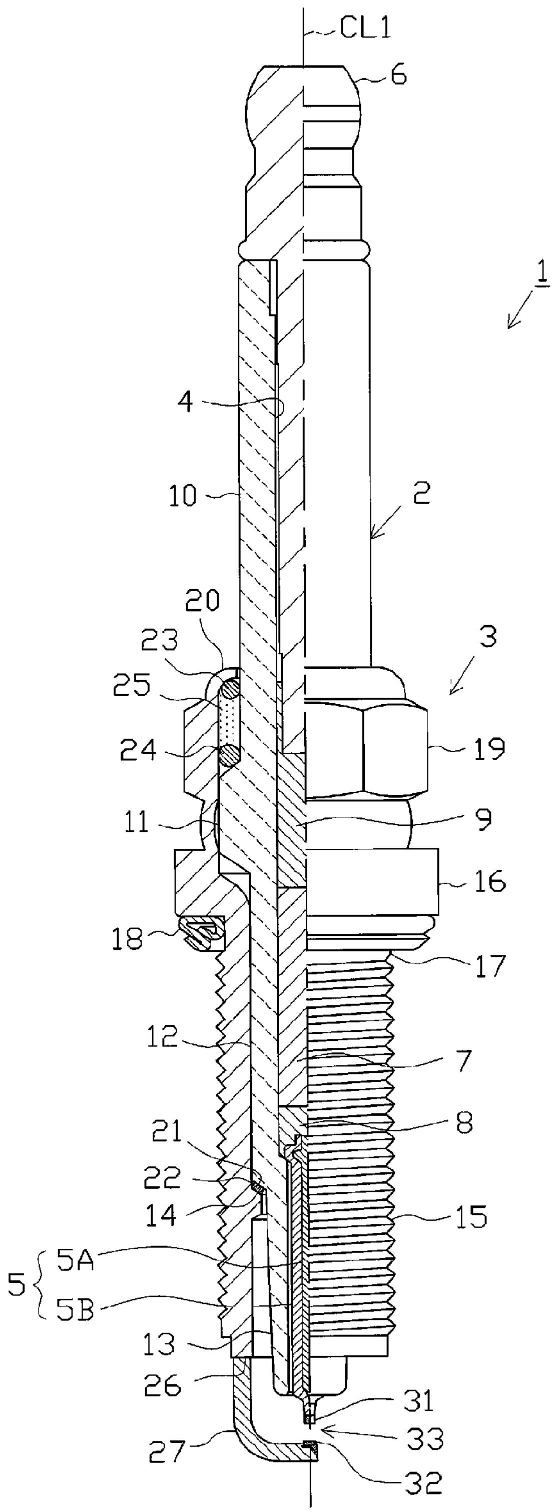
FIG. 1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4
2
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9
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16
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17
12
7
21
8
22
14
15
5A
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5B
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31
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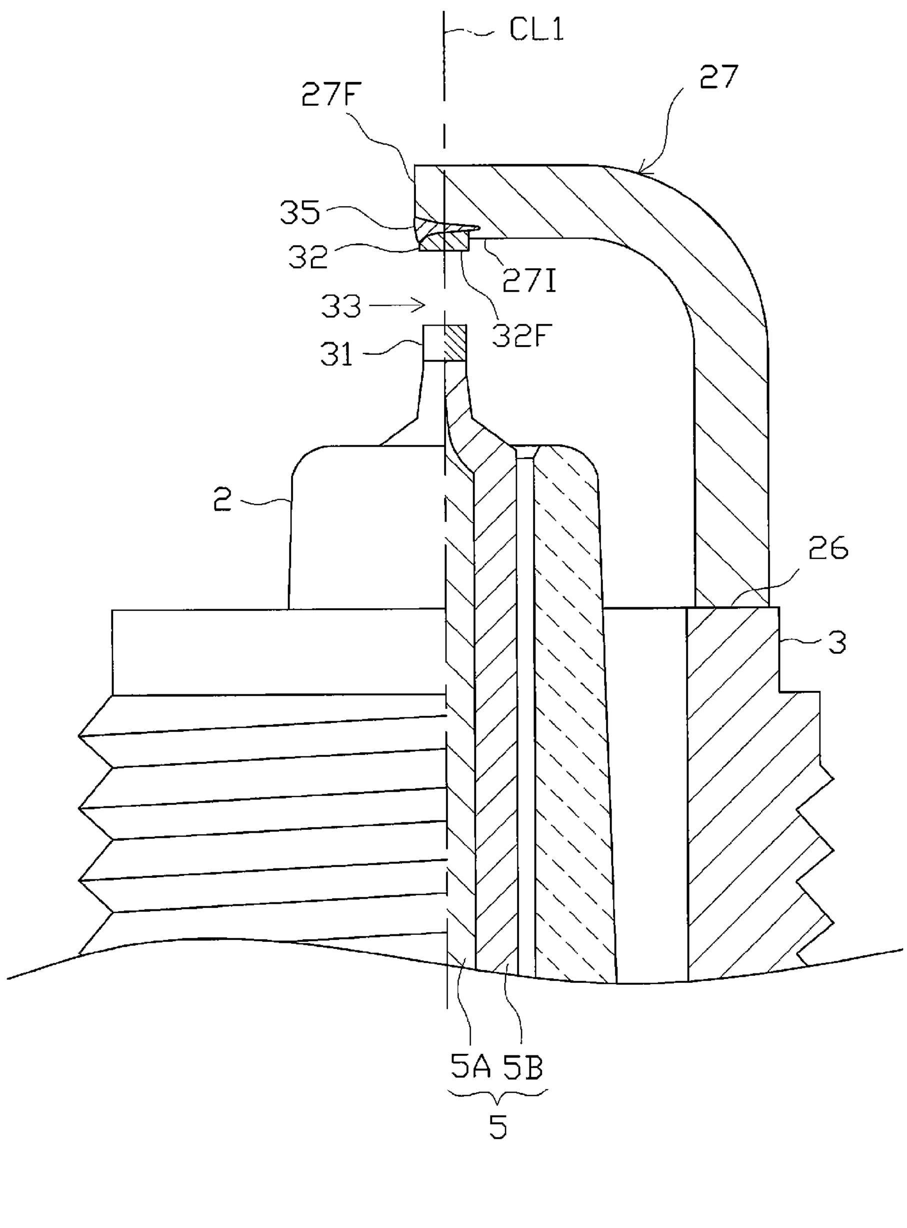
27
32

FIG. 2



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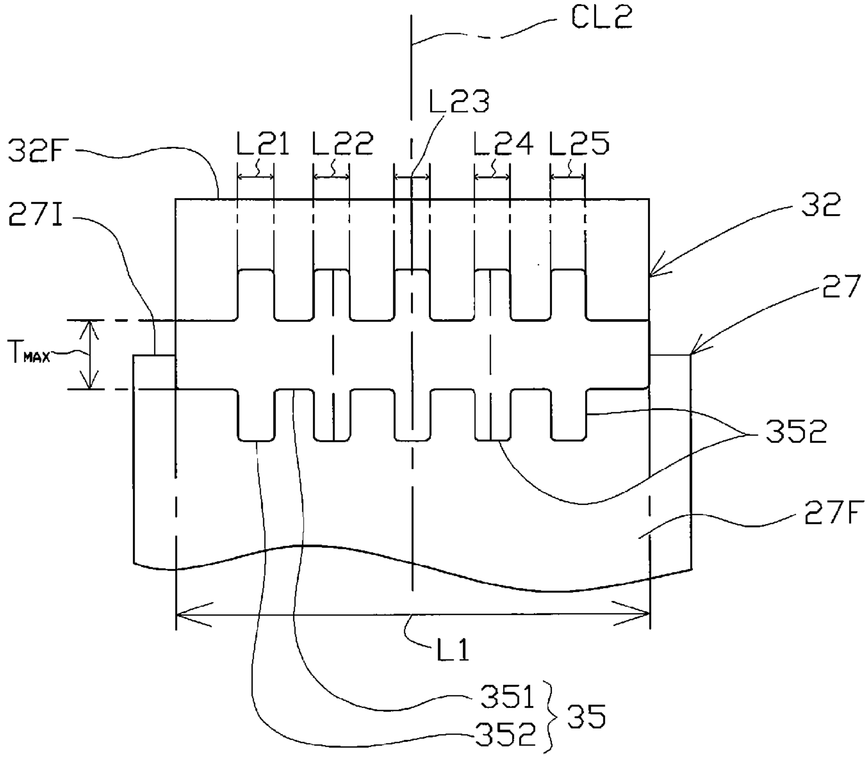
CL2
L23
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L21
L22
L24
L25
32
27I
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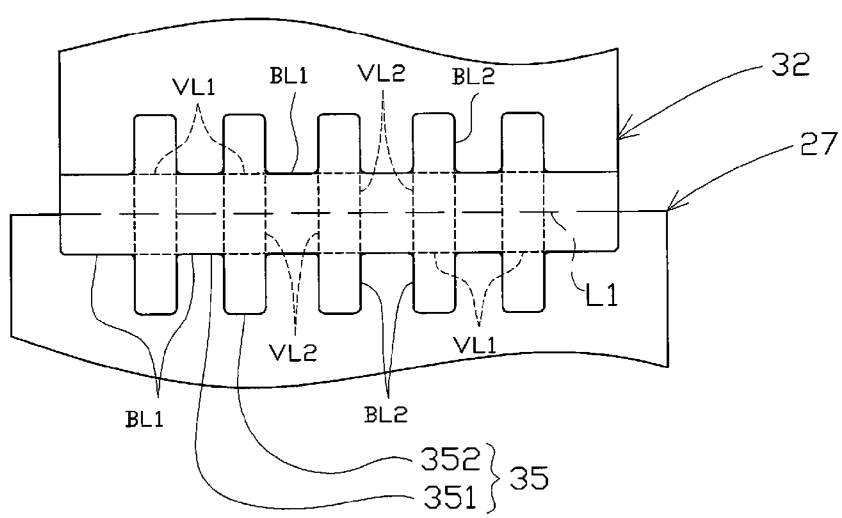
TMAX
352
27F
L1
351
352
35

FIG. 4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VL2
BL2
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VL2
VL1
BL1
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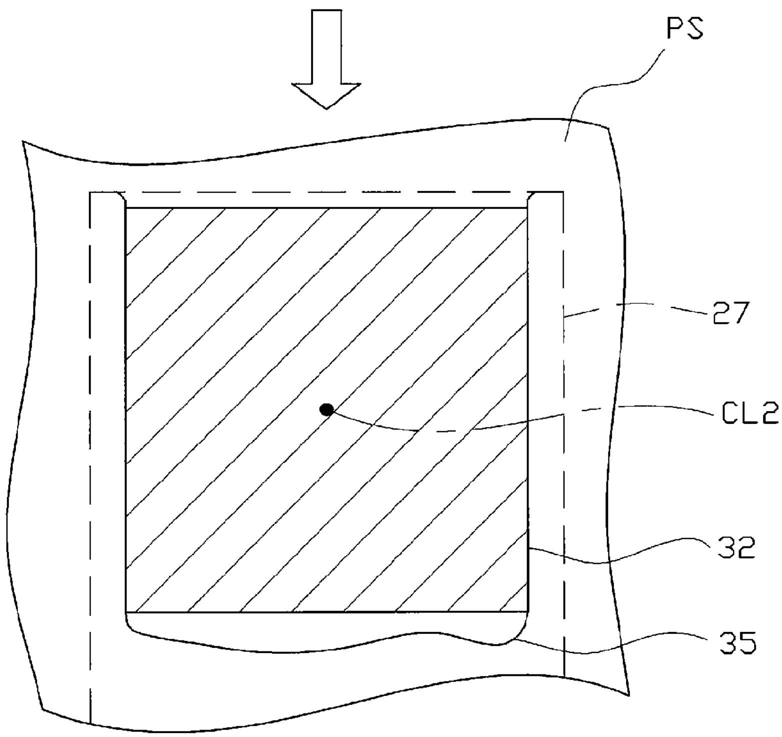
352
351
35

FIG. 5



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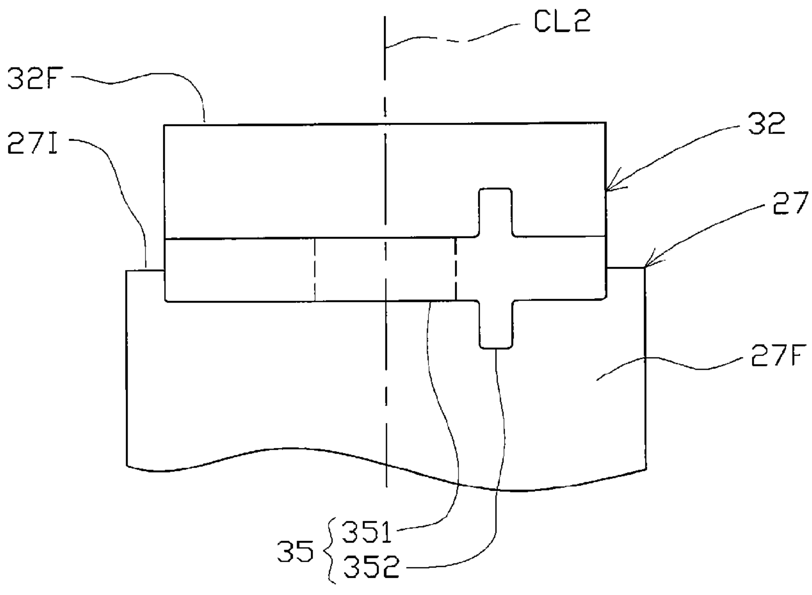

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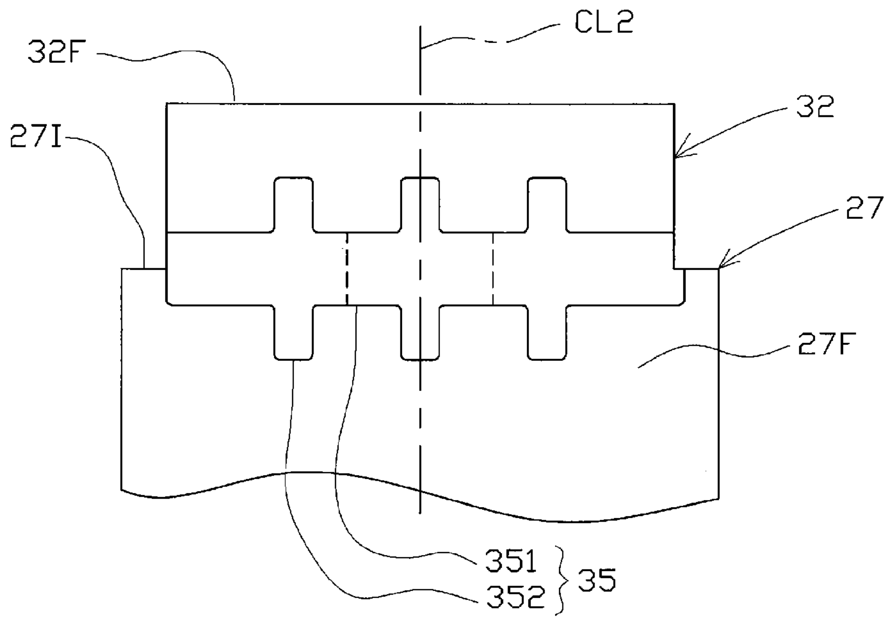

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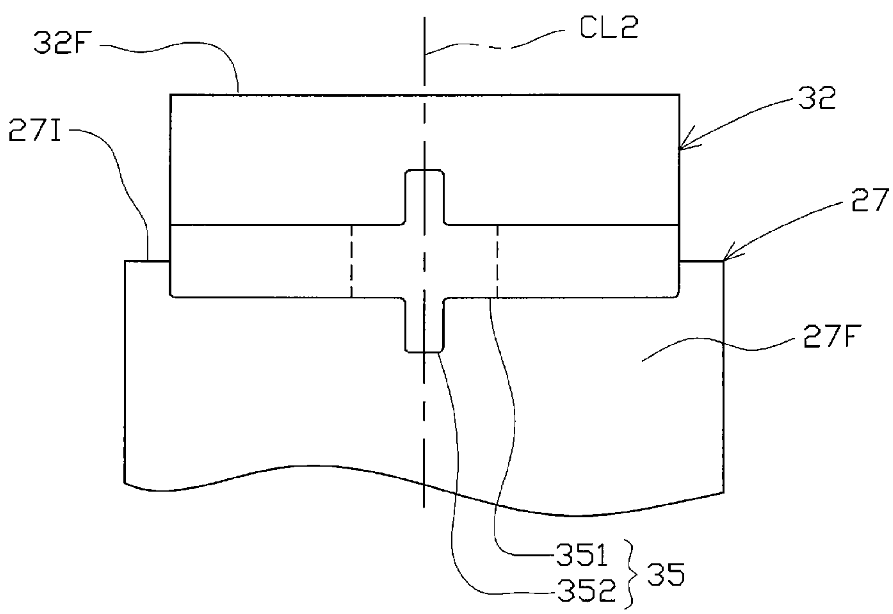

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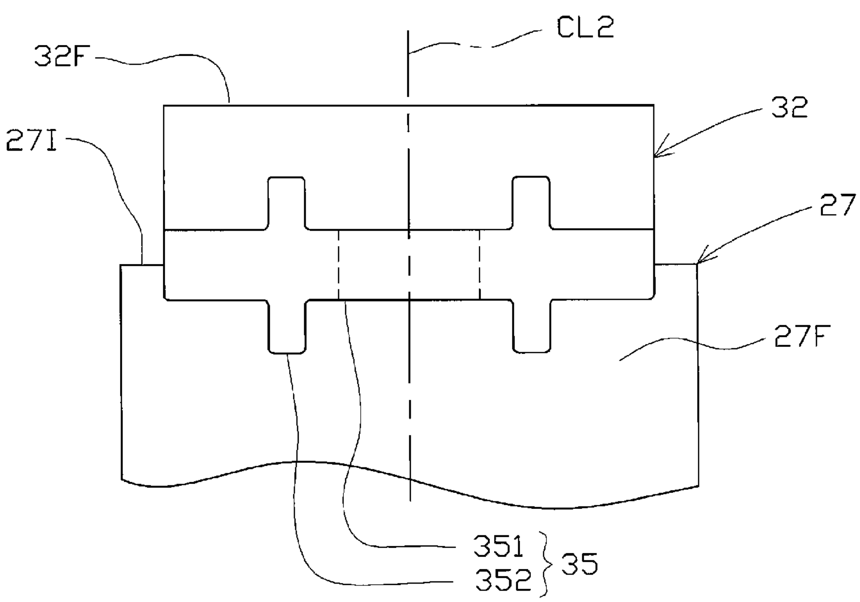

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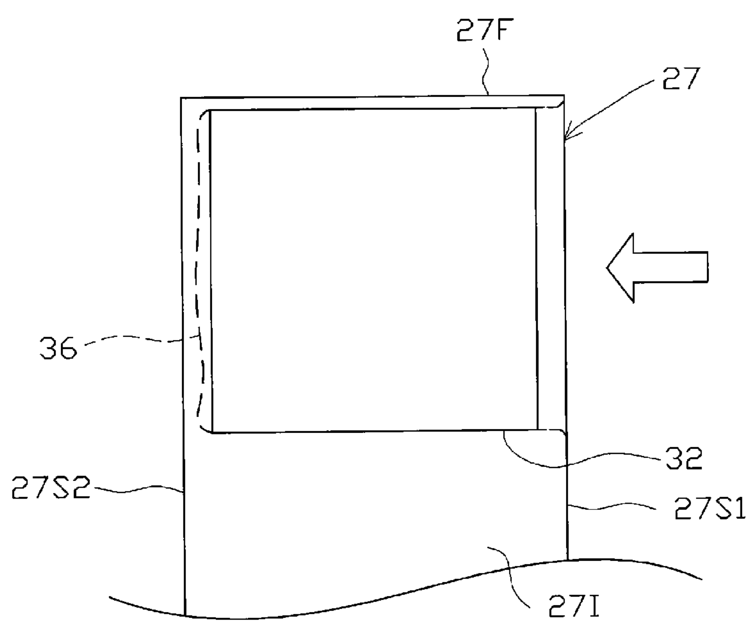

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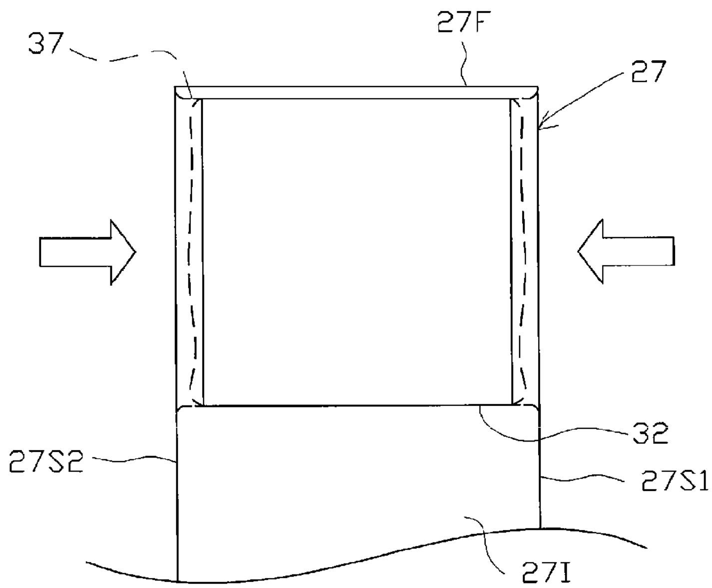

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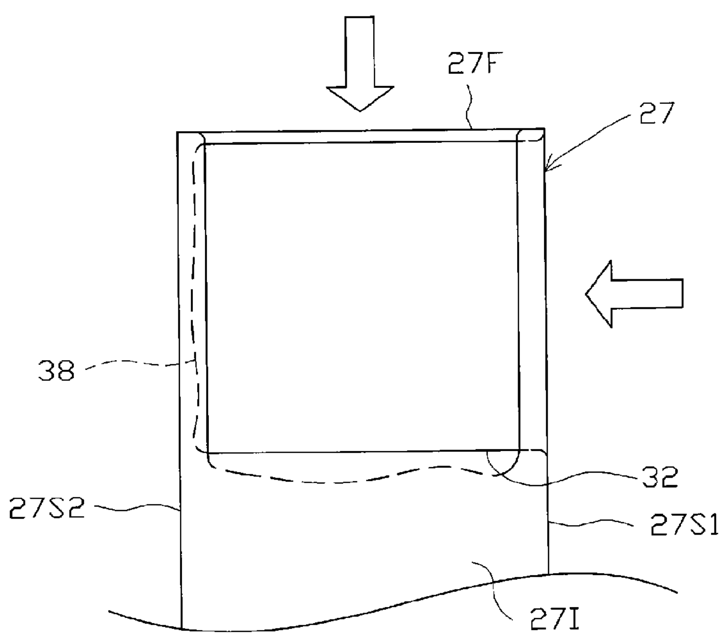

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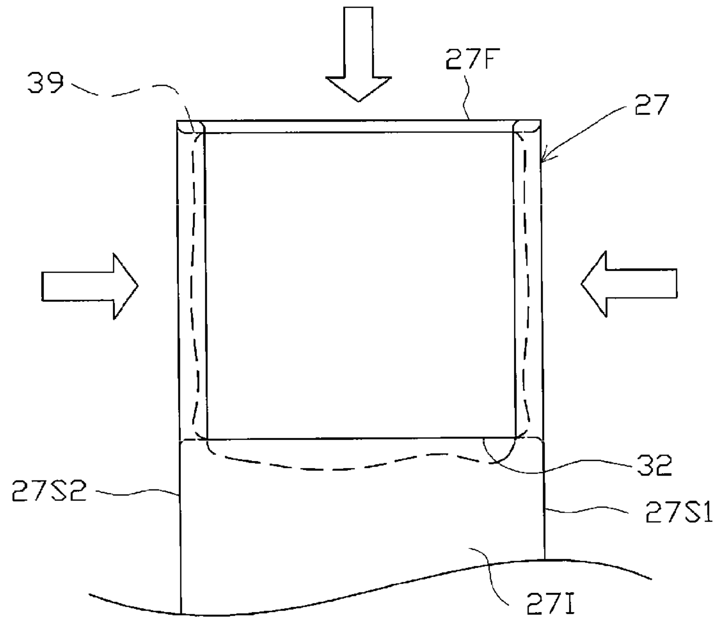

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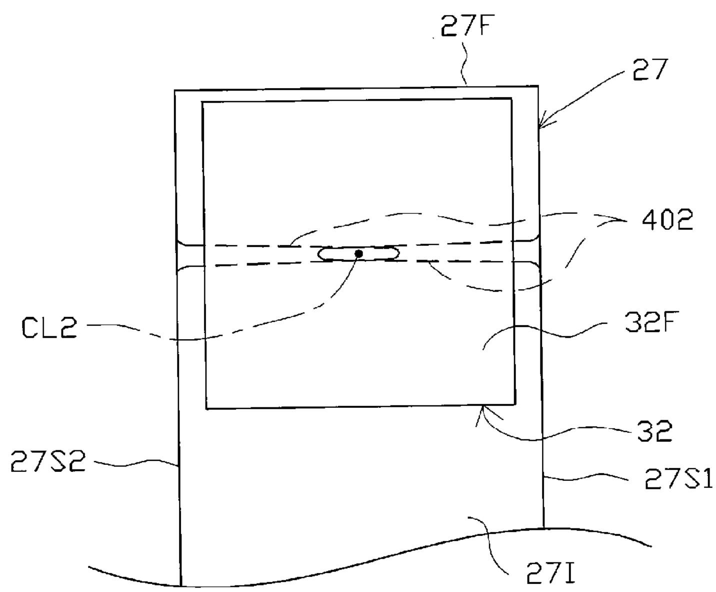

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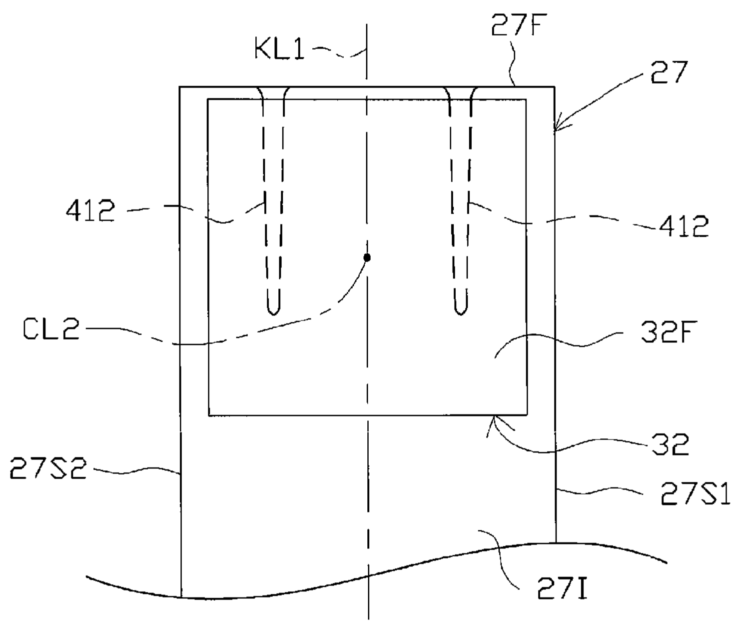
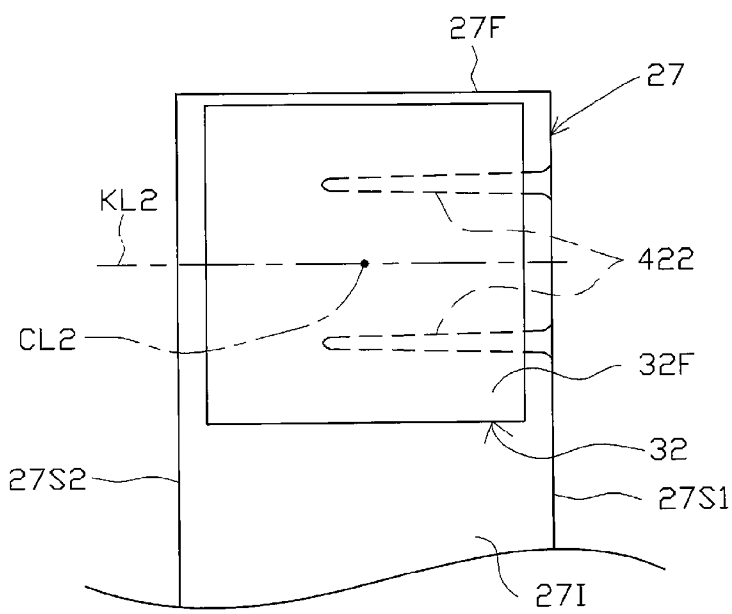

27F
KL1
27
412
412
CL2
32F
32
27S2
27S1
27I

FIG. 16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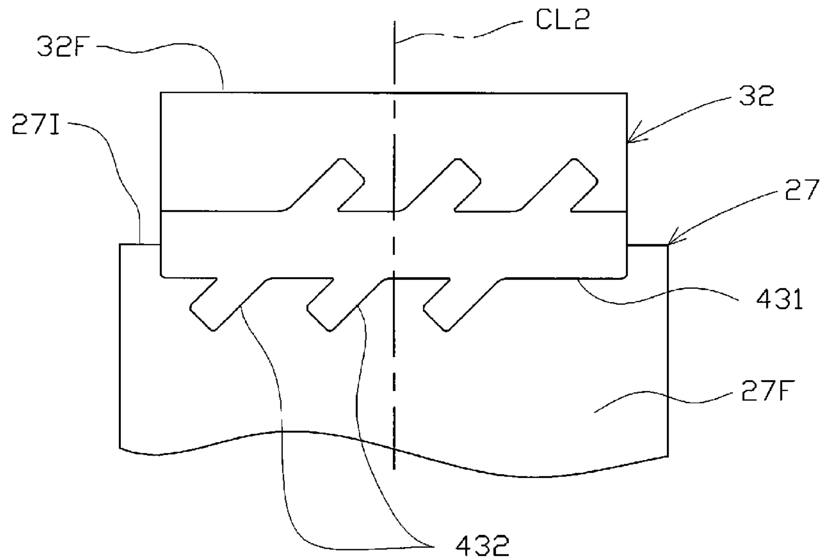
32
27S2
27S1
27I

FIG. 17



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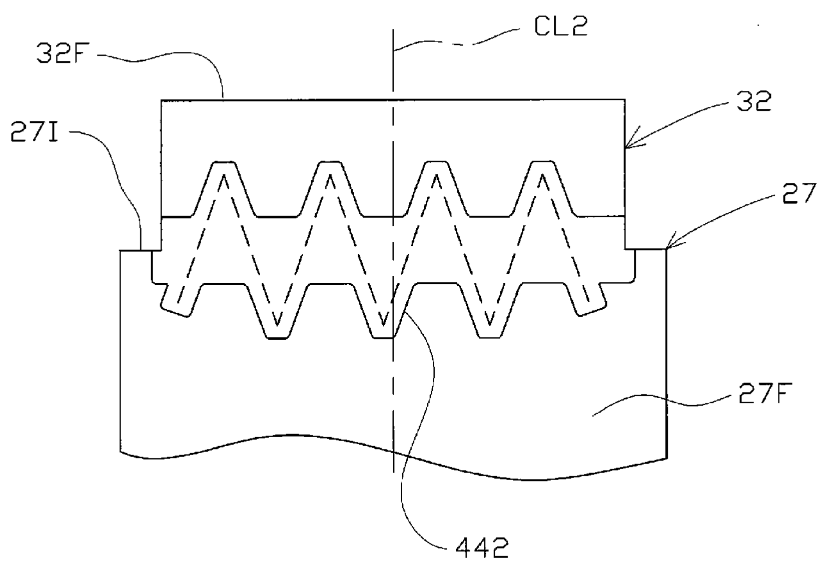

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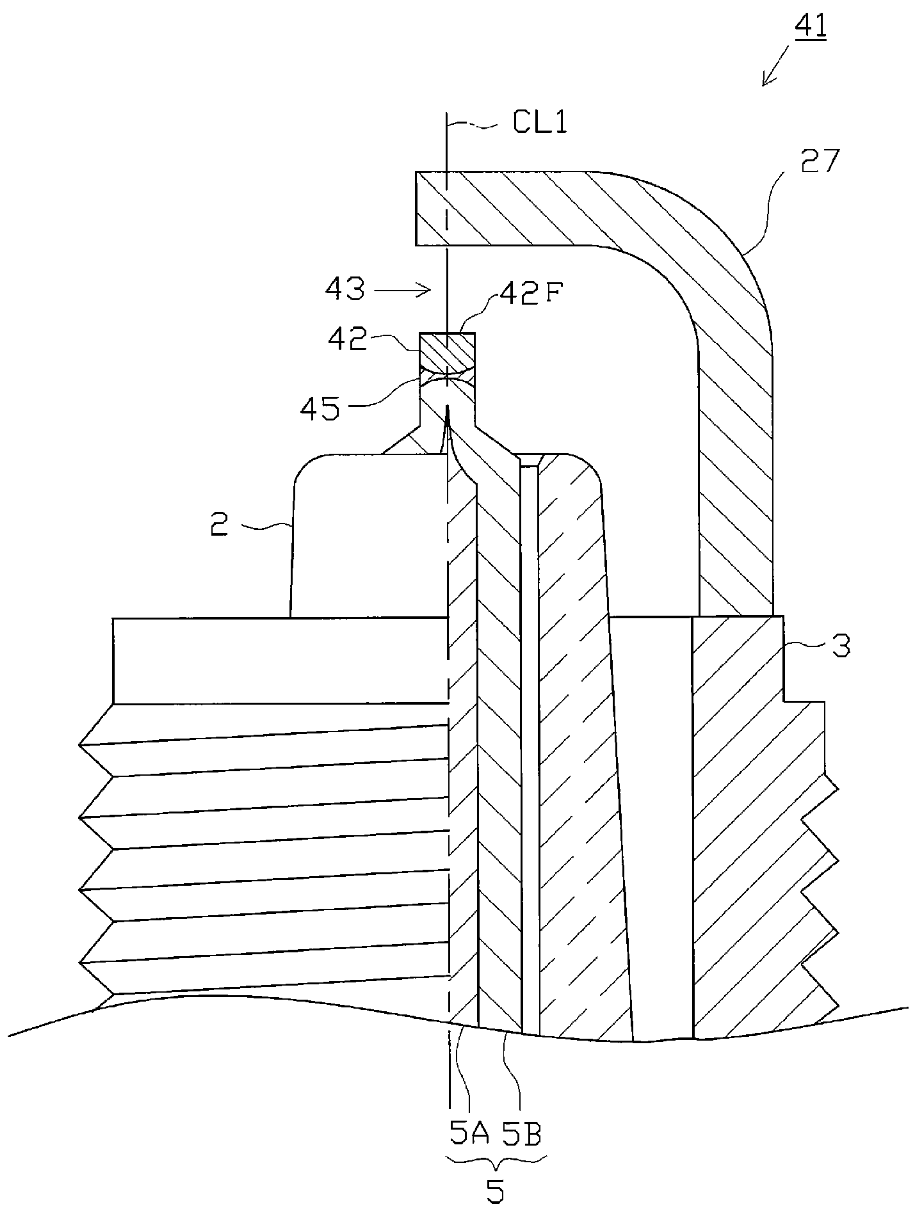

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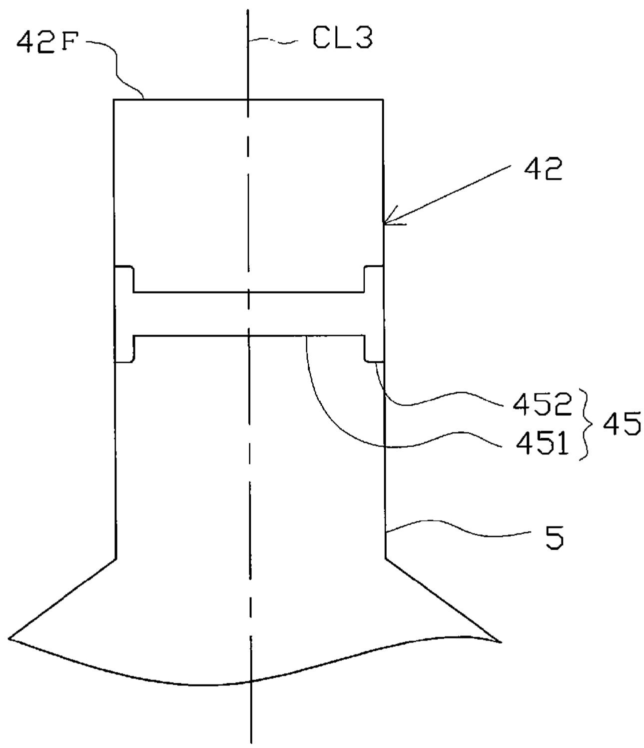

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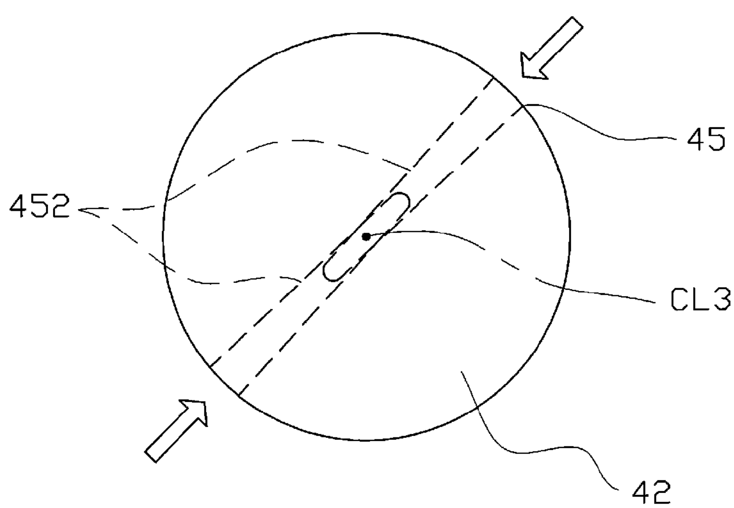

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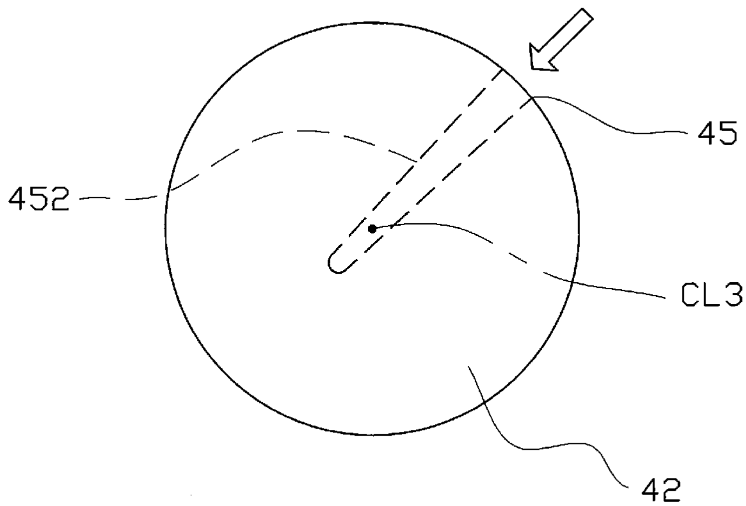

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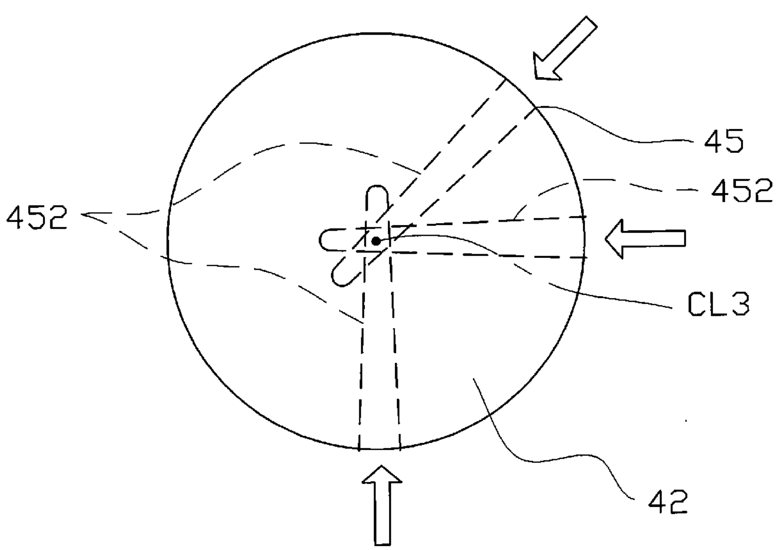

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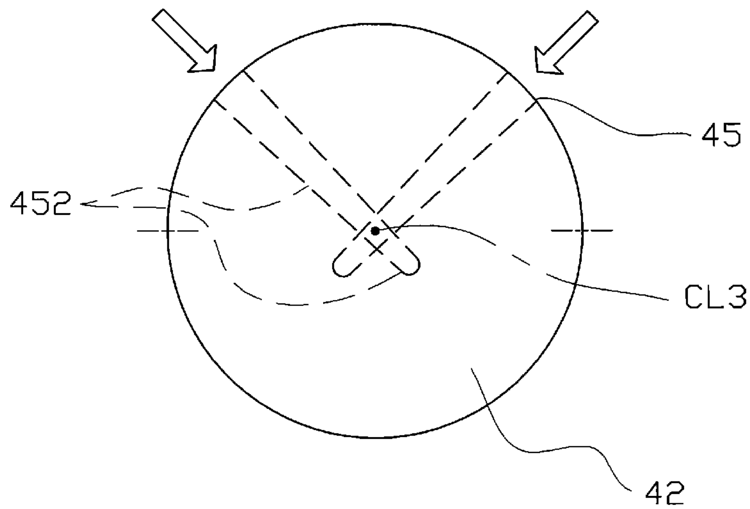

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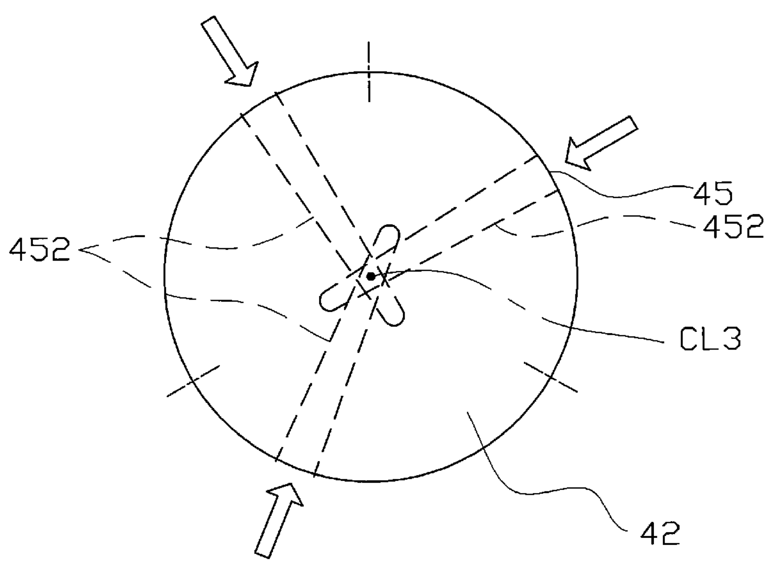

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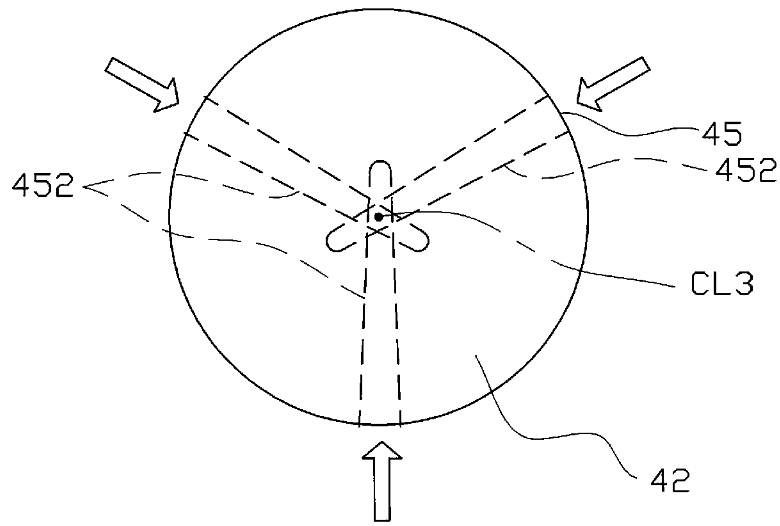

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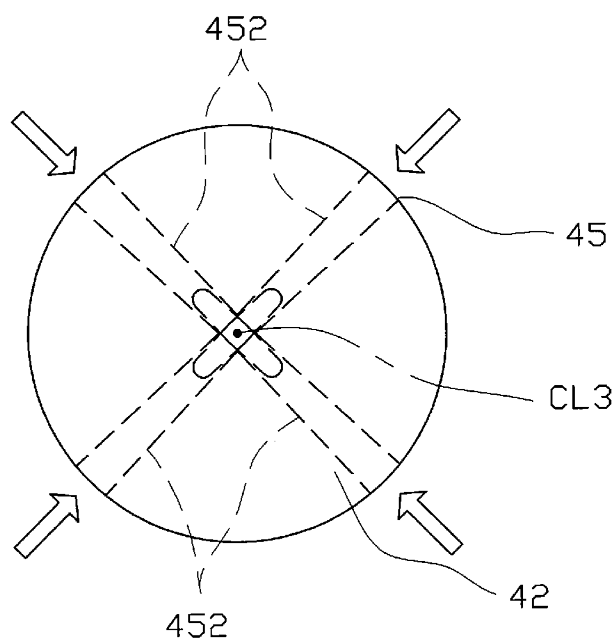

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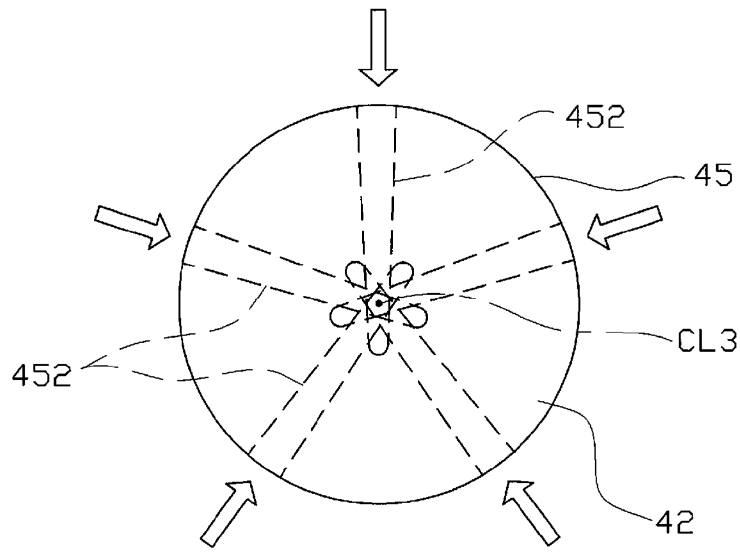

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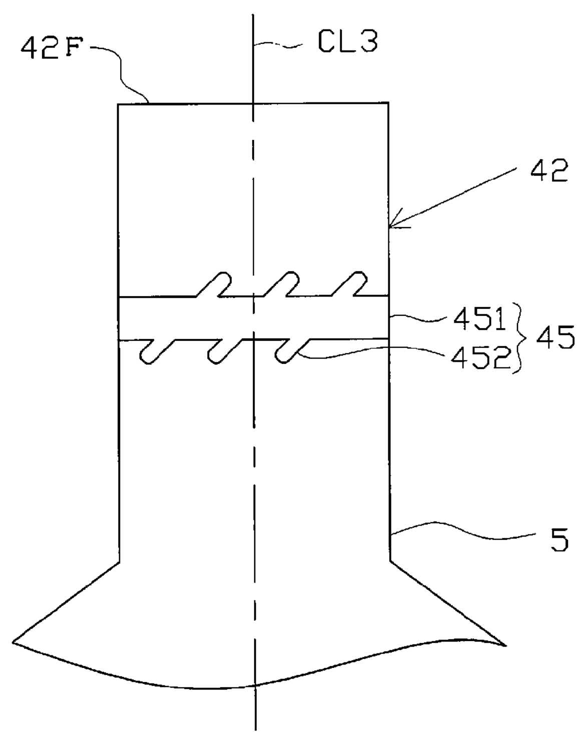

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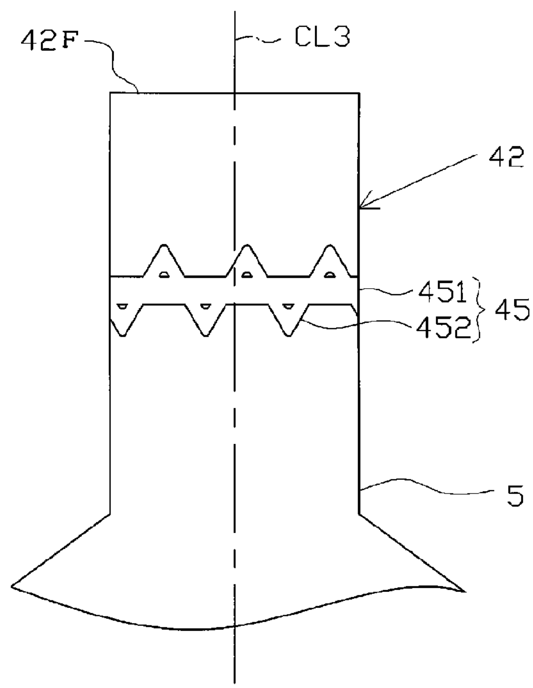
42F
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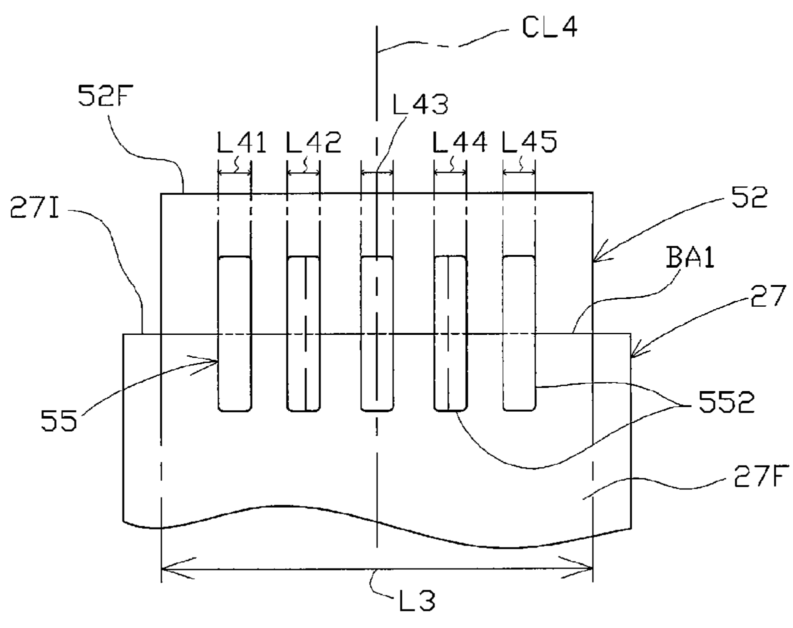
42
451
452
45
5

FIG. 31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55
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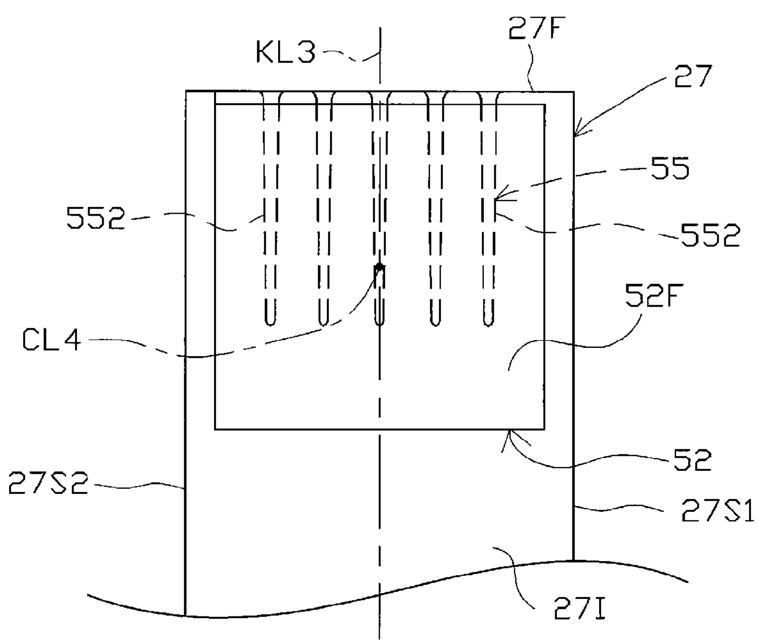
27F
L3

FIG. 32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27S2
27S1
27I

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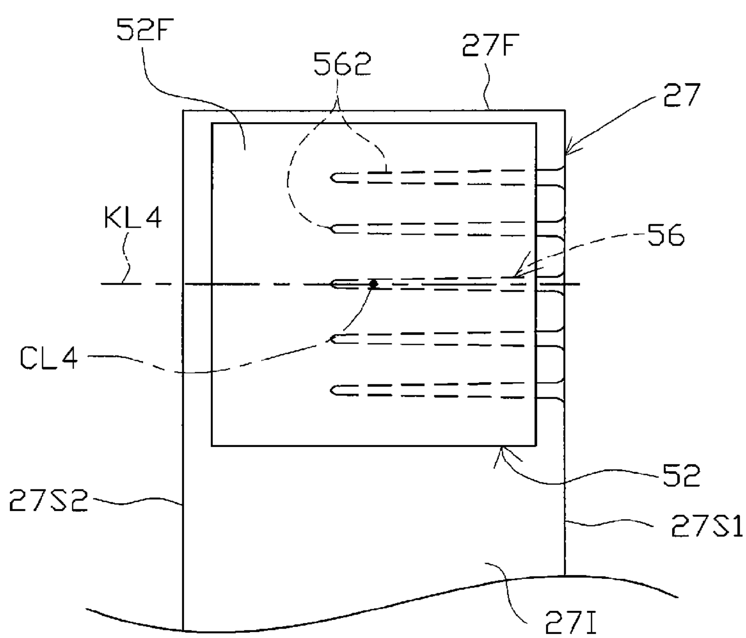
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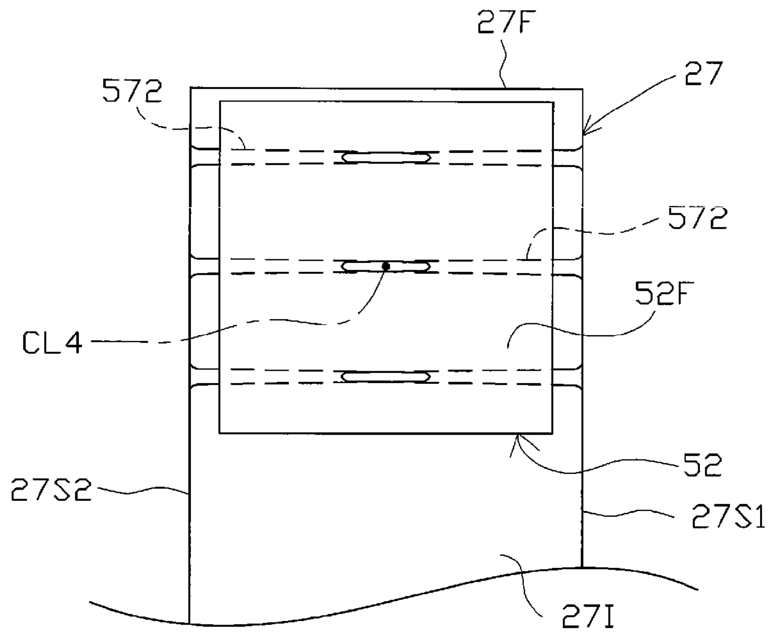
27S2
27S1
27I

FIG. 34



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572
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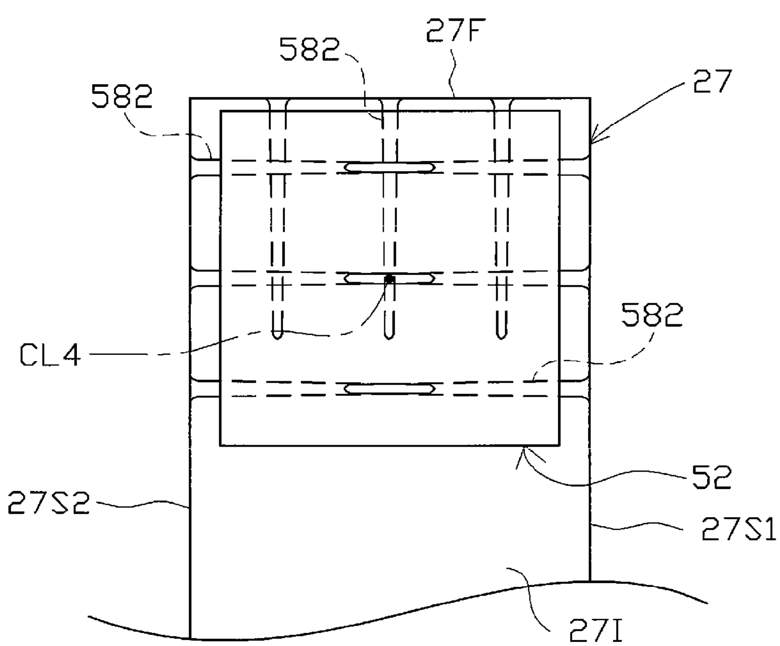
CL4
52
27S2
27S1
27I

FIG. 35



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582
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27S1
27I

FIG. 36

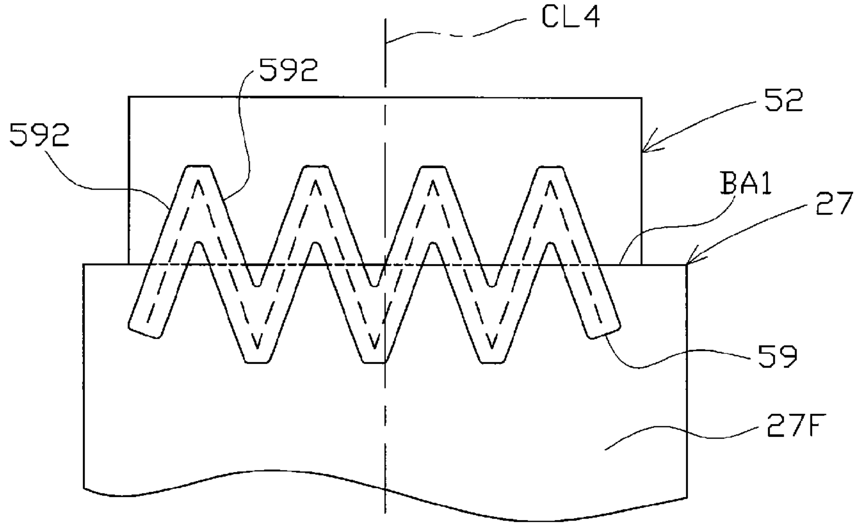


FIG. 37

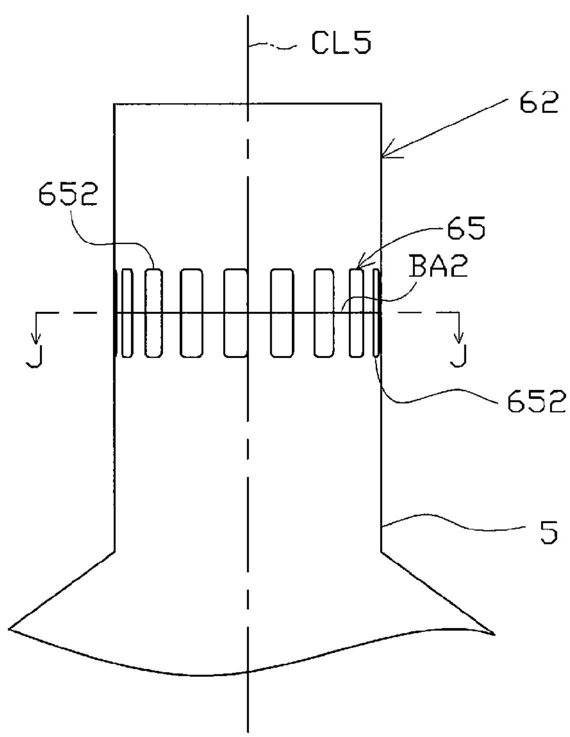
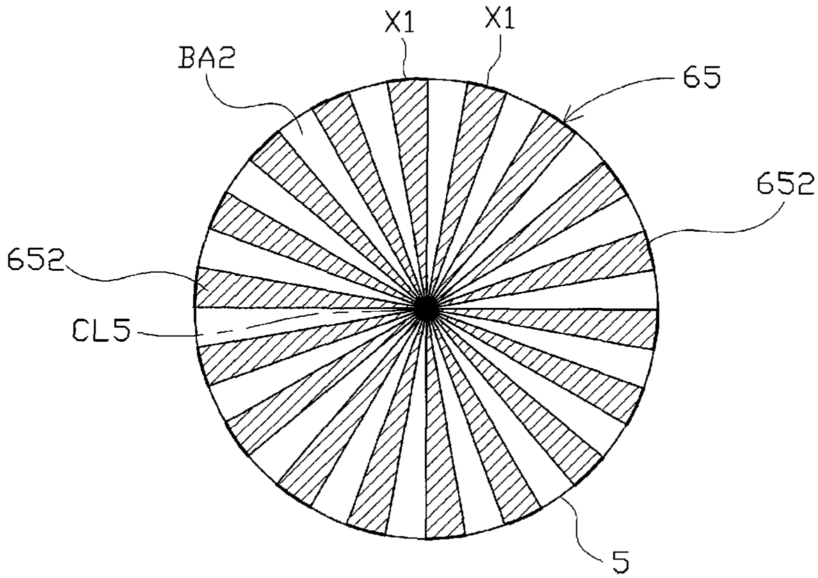


FIG. 38



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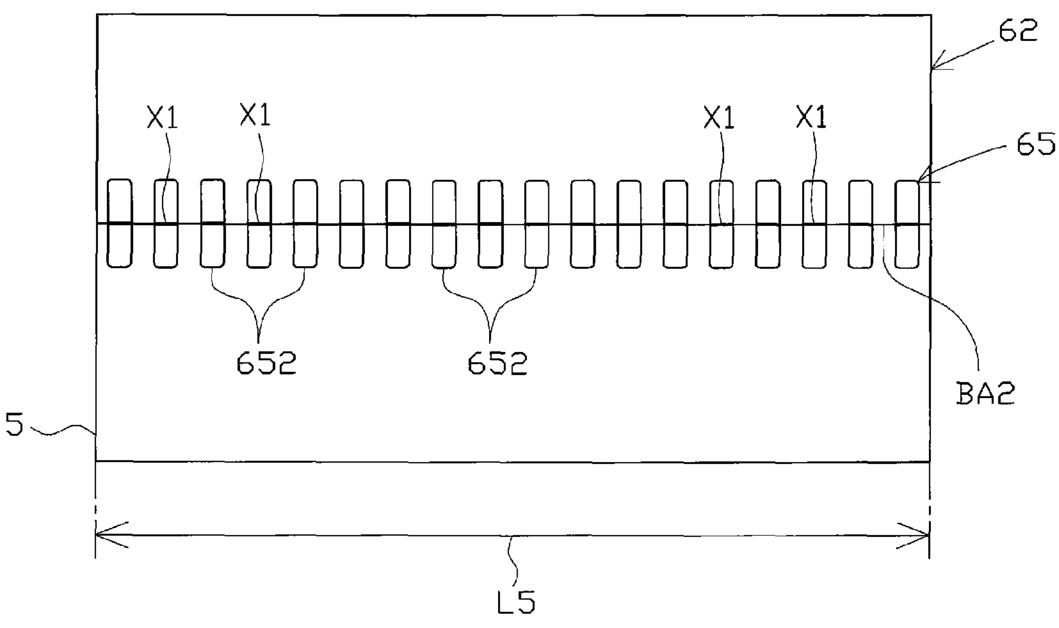

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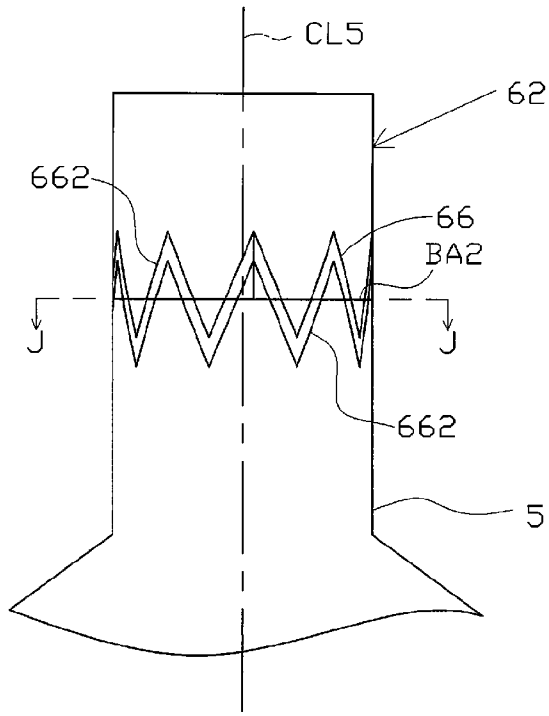

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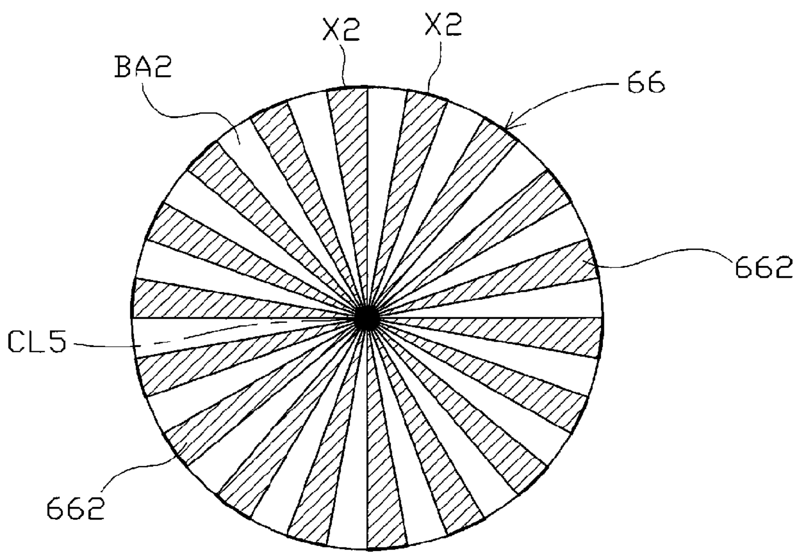

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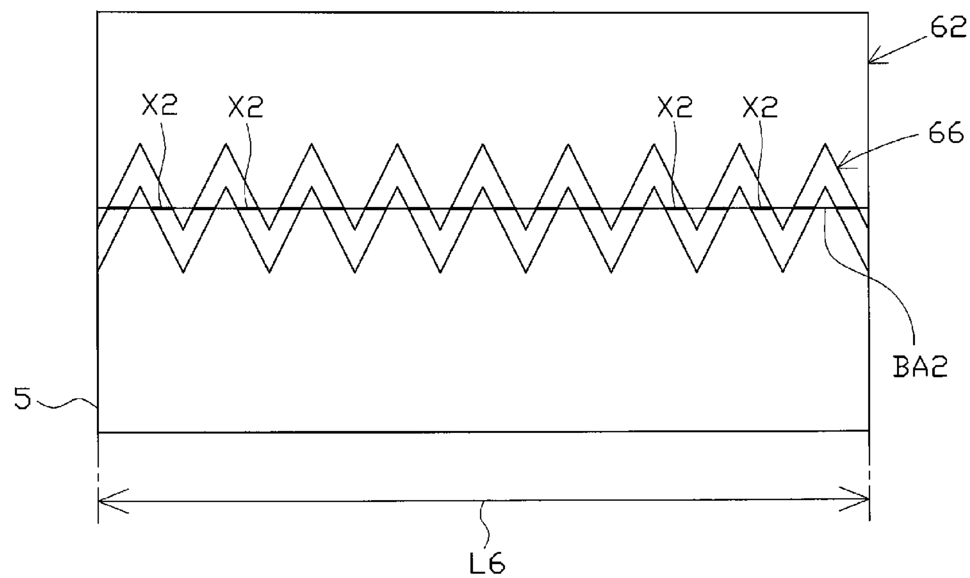
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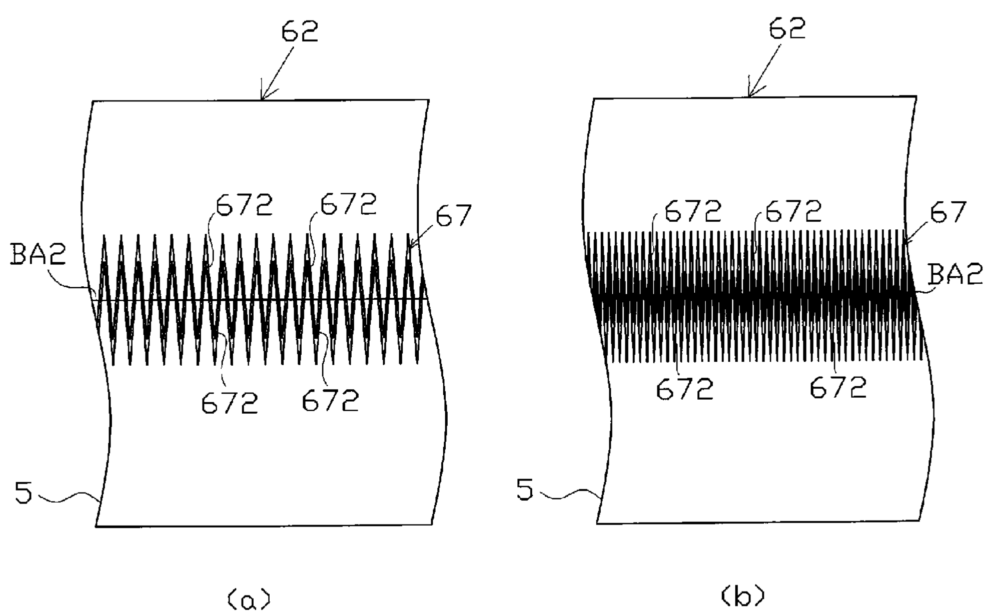
X2
X2
X2
66
BA2
5
L6

FIG. 43


62
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672
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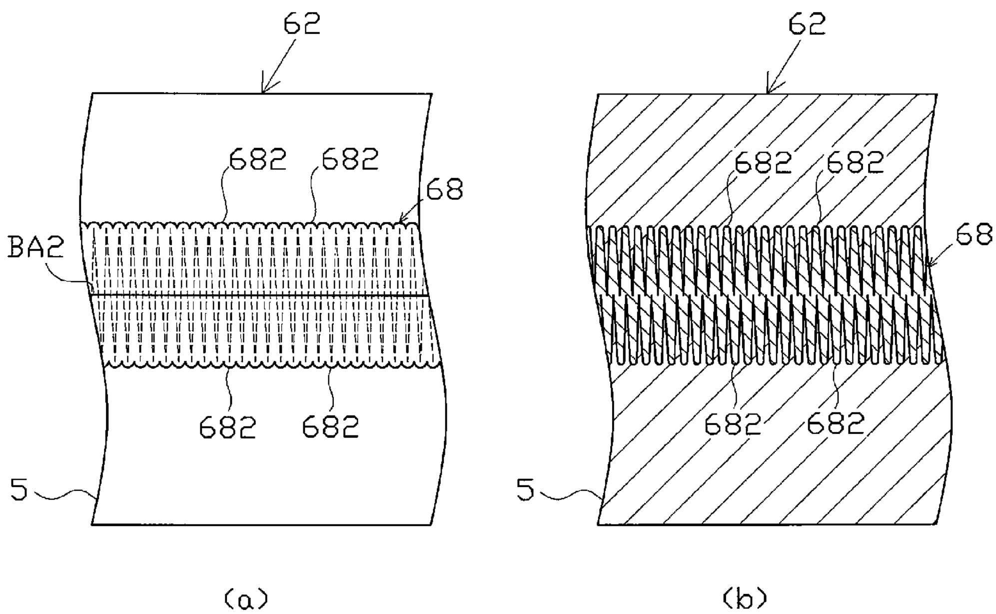
67
BA2
672
672
5
(b)

FIG. 44



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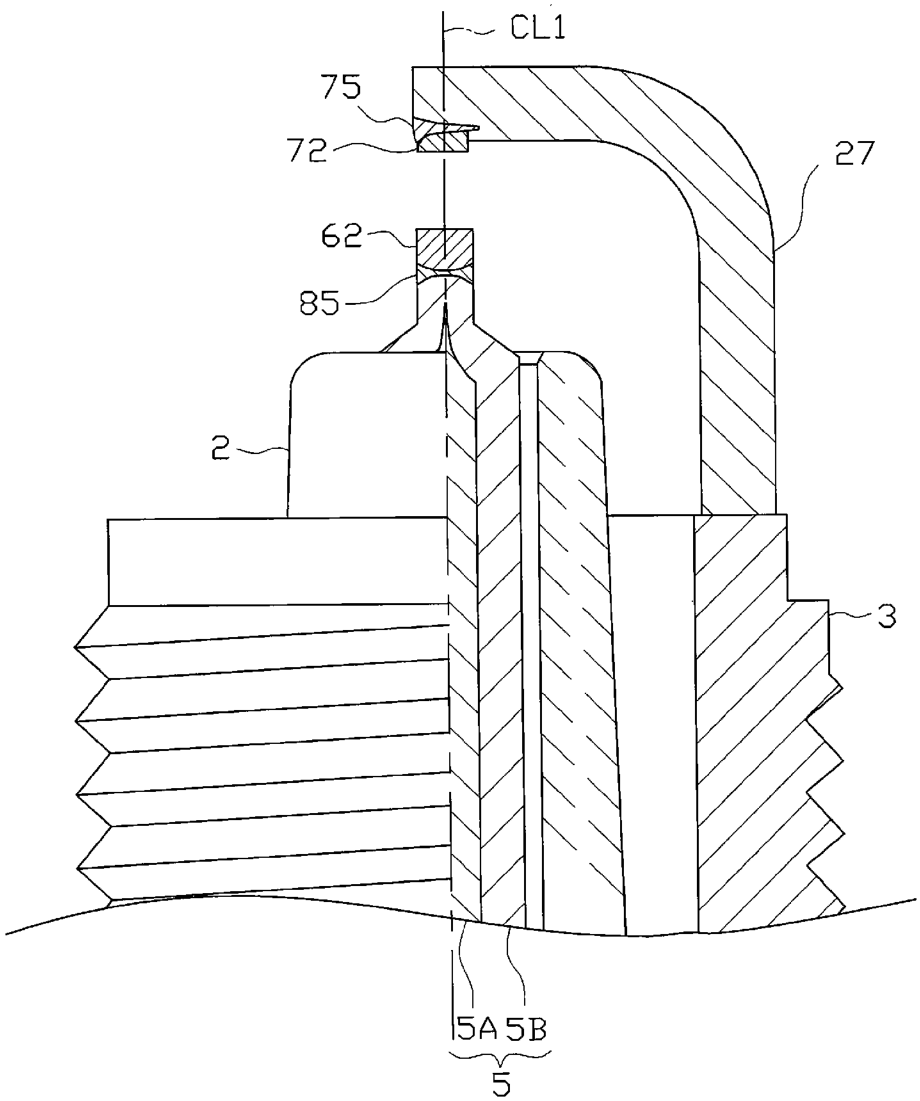

FIG. 46

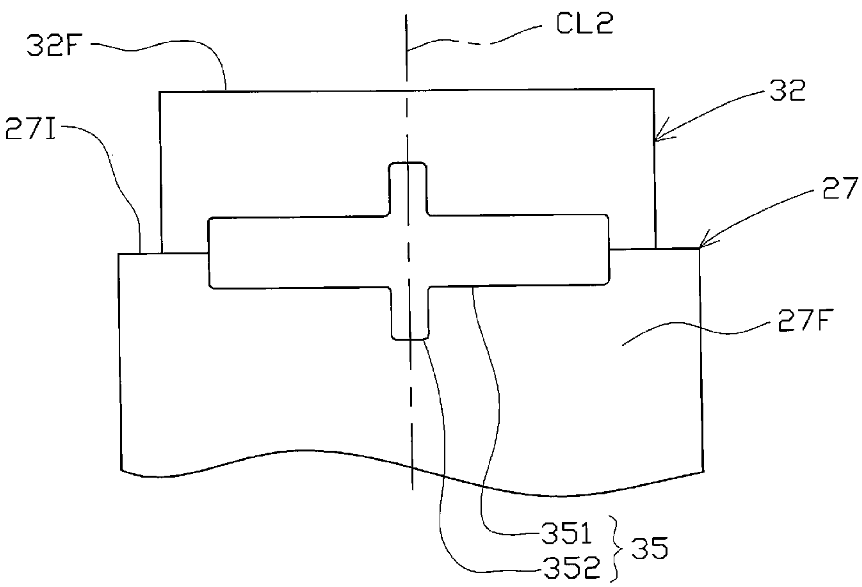
CL2
32F
32
27I
27
27F
351
352
35

FIG. 47

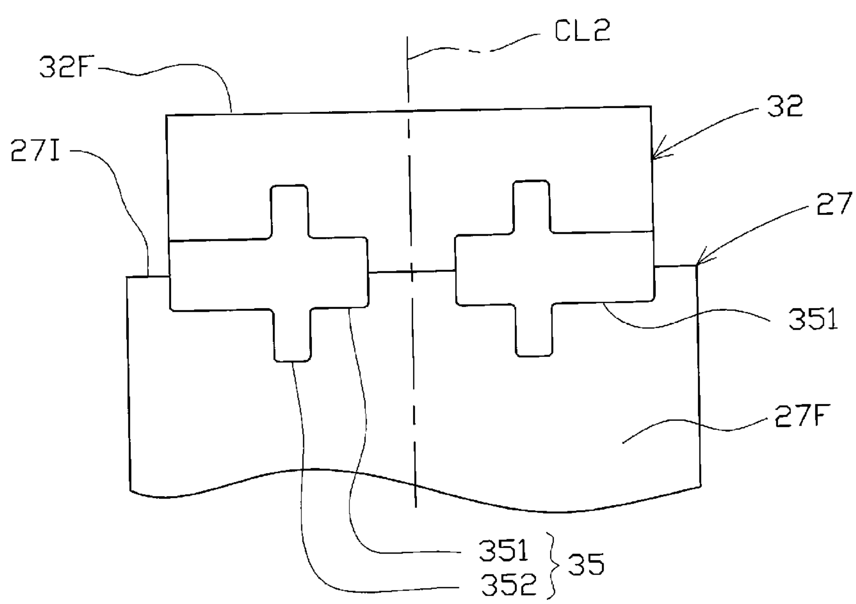
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FIG. 48

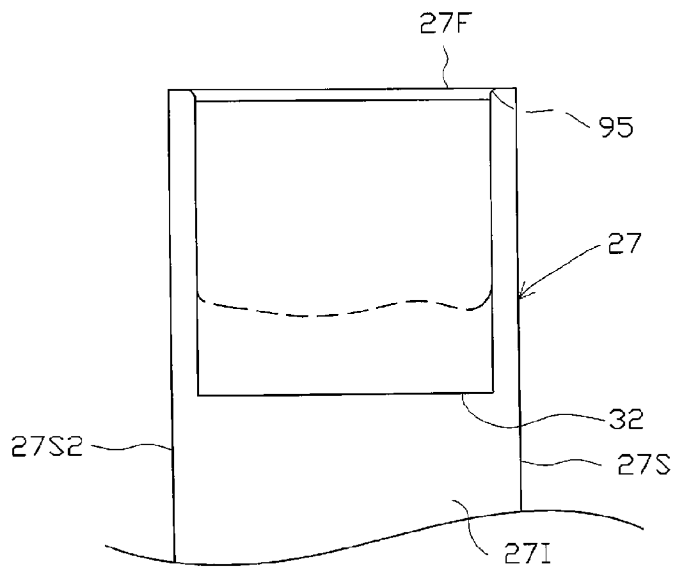
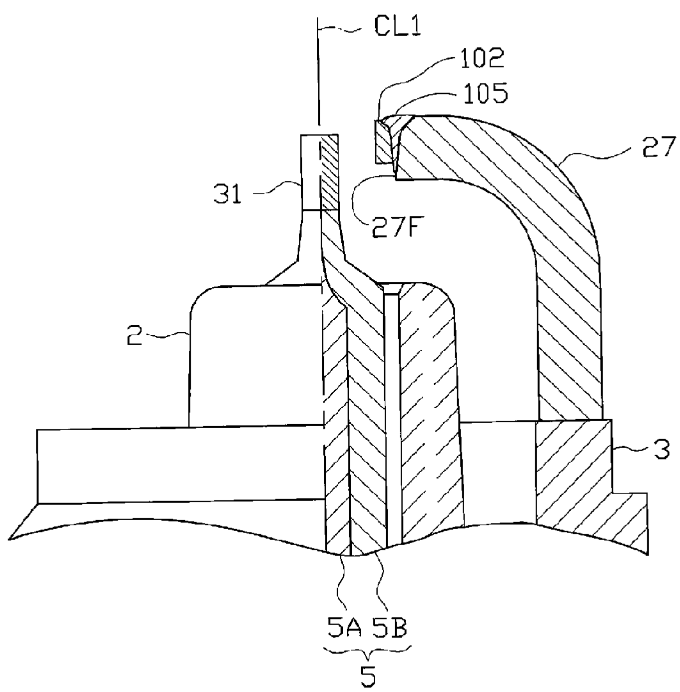


FIG. 49



SPARK PLUG HAVING FUSION ZONE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a National Stage of International Application No. PCT/JP2011/076569 filed Nov. 17, 2011, claiming priority based on Japanese Patent Application No. 2010-256523 filed Nov. 17, 2010, the contents of all of which are incorporated herein by reference in their entirety.

TECHNICAL FIELD

The present invention relates to a spark plug for use in an internal combustion engine, etc.

BACKGROUND ART

A spark plug for use in a combustion apparatus, such as an internal combustion engine, includes, for example, a center electrode extending in the direction of an axis, an insulator provided around the center electrode, a tubular metallic shell attached to the outside of the insulator, and a ground electrode whose proximal end portion is joined to a forward end portion of the metallic shell. The ground electrode is bent at its substantially intermediate portion in such a manner that its distal end portion faces a forward end portion of the center electrode, thereby forming a spark discharge gap between the forward end portion of the center electrode and a distal end portion of the ground electrode.

In recent years, there has been known a technique for improving erosion resistance by providing a noble metal tip at a forward end portion of the center electrode and/or a distal end portion of the ground electrode in a region adapted to form the spark discharge gap. In joining the noble metal tip to the ground electrode or the like, generally, laser welding by means of a YAG laser is used (refer to, for example, Patent Document 1). Specifically, a laser beam is intermittently radiated to the circumference or perimeter of the boundary between the noble metal tip and the ground electrode or the like, thereby joining the noble metal tip to the ground electrode or the like through formation of a fusion zone where components of the members are fused together.

PRIOR ART DOCUMENT

Patent Document

Patent Document 1: Japanese Patent Application Laid-Open (kokai) No. 2003-17214

SUMMARY OF THE INVENTION

Problems to be Solved by the Invention

However, in order to make the fusion zone penetrate deep into the ground electrode or the like so as to maintain sufficient joining strength, increasing radiation energy is required; however, in the case of use of YAG laser, this leads to the fusion zone having a relatively large volume. Accordingly, the fusion zone may be exposed to the spark discharge gap, or the noble metal tip may be melted in a relatively large amount in the course of forming the fusion zone, resulting in the noble metal tip becoming greatly thin. As a result, an action or effect of improving erosion resistance through provision of the noble metal tip may fail to be sufficiently exhibited.

In view of this, the inventor of the present invention carried out extensive studies and found the following: by use of a high-energy laser beam, such as a fiber laser beam, in place of a YAG laser beam, while a sufficiently wide weld zone is formed between the noble metal tip and the ground electrode or the like, the weld zone can have a relatively small volume, whereby the effect of improving erosion resistance is sufficiently exhibited.

However, the inventor of the present invention carried out further studies and found the following: when a fiber laser beam or the like is used, the fusion zone becomes globally thin; thus, the fusion zone encounters difficulty in absorbing a stress difference between the noble metal tip and the ground electrode or the like associated with thermal expansion, and in turn, separation of the noble metal tip could arise.

The present invention has been conceived in view of the above circumstances, and an object of the invention is to provide a spark plug which can effectively restrain the separation of a noble metal tip, while sufficiently exhibiting the effect of improving erosion resistance through provision of the noble metal tip.

Means for Solving the Problems

Configurations suitable for solving the above problems will next be described in itemized form. If needed, actions and effects peculiar to the configurations will be described additionally.

Configuration 1. A spark plug of the present configuration comprises:

a rodlike center electrode extending in a direction of an axis;

a tubular insulator provided around the center electrode;

a tubular metallic shell provided around the insulator;

a ground electrode whose proximal end is welded to the metallic shell and whose distal end faces the center electrode; and

a columnar noble metal tip formed from a noble metal alloy and provided on at least one object member of the center electrode and the ground electrode.

One end surface of the noble metal tip is joined to the object member via a fusion zone formed through radiation of a laser beam or an electron beam from a side toward a side surface of the noble metal tip.

The spark plug is characterized in that the fusion zone comprises:

a first fusion zone formed through radiation of the laser beam or the electron beam to a boundary between the object member and the one end surface of the noble metal tip along a perimetrical direction of the noble metal tip, and

a second fusion zone formed through radiation of the laser beam or the electron beam from the side from which the laser beam or the electron beam has been radiated in forming the first fusion zone, and intersecting with the first fusion zone.

The first fusion zone and the second fusion zone may be formed continuously or intermittently.

According to the above configuration 1, in addition to the first fusion zone formed between the noble metal tip and the object member (the ground electrode or the center electrode), the second fusion zone is formed in such a manner as to intersect with the first fusion zone. That is, by virtue of the presence of the second fusion zone, at least a portion of the fusion zone is thicker than the first fusion zone. Therefore, the thick portion, which is superior to the first fusion zone in the capability of absorbing a stress difference, can effectively absorb an excess stress difference between the noble metal tip and the object member associated with thermal expansion which the first fusion zone has failed to absorb.

Furthermore, a stress difference which arises along a boundary surface between the fusion zone and the noble metal tip or between the fusion zone and the object member may cause movement of the fusion zone in relation to the object member or the noble metal tip, potentially resulting in separation of the noble metal tip; however, the provision of the second fusion zone renders the boundary surface partially protrusive. Therefore, the protrusion functions as, so to speak, a wedge, whereby a relative movement of the fusion zone along the boundary surface can be more reliably restrained.

Also, according to the above configuration 1, as compared with the case where the first fusion zone is merely rendered thick, the volume of the fusion zone can be sufficiently small. Thus, a portion of the noble metal tip which fuses in the joining process can be reduced, whereby there can be more reliably prevented the exposure of the fusion zone to a spark discharge gap and a situation in which the noble metal tip becomes excessively thin.

As mentioned above, according to the above configuration 1, while the effect of improving erosion resistance through provision of the noble metal tip is sufficiently exhibited, the effect of effectively absorbing a stress difference and the effect of preventing movement of the fusion zone through provision of the second fusion zone can achieve synergy, whereby the separation of the noble metal tip can be quite effectively prevented.

Configuration 2. A spark plug of the present configuration is characterized in that, in the above configuration 1, the noble metal tip is joined to at least an inner side surface of the ground electrode, and the fusion zone is formed through radiation of the laser beam or the electron beam from a side toward at least one of a distal end surface and opposite side surfaces of the ground electrode, and

when the noble metal tip and the fusion zone are viewed from the side from which the laser beam or the electron beam has been radiated to the surface of the ground electrode,

assuming that a portion of the fusion zone located between the ground electrode and the noble metal tip is equally divided into three segmental regions along a width direction of the noble metal tip, the first fusion zone and the second fusion zone are in contact with each other in at least a center one of the three segmental regions.

The expression "when . . . viewed from the side from which the laser beam or the electron beam has been radiated to the surface of the ground electrode" can be said to mean "when . . . viewed from a direction orthogonal to the side surface of the ground electrode associated with the side from which the laser beam or the electron beam has been radiated."

According to the above configuration 2, since the second fusion zone is provided at the center of the fusion zone, an excess stress difference which the first fusion zone fails to absorb is more reliably applied to the thick portion (where the second fusion zone exists) of the fusion zone, the thick portion being superior in the capability of absorbing a stress difference. As a result, a stress difference can be more effectively absorbed, and thus, the separation of the noble metal tip can be more reliably prevented.

In order to further enhance the effect of absorbing a stress difference by the fusion zone, desirably, as viewed from a side from which the laser beam or the like is radiated, the first fusion zone is formed along the entire width of the noble metal tip.

Configuration 3. A spark plug of the present configuration is characterized in that, in the above configuration 1 or 2, the noble metal tip is joined to at least the ground electrode, and

the fusion zone is formed through radiation of the laser beam or the electron beam from a side toward at least one of a distal end surface and opposite side surfaces of the ground electrode, and

when the noble metal tip and the fusion zone are viewed from the side from which the laser beam or the electron beam has been radiated to the surface of the ground electrode,

assuming that a portion of the fusion zone located between the ground electrode and the noble metal tip is equally divided into three segmental regions along a width direction of the noble metal tip, the first fusion zone and the second fusion zone are in contact with each other in at least opposite end ones of the three segmental regions.

According to the above configuration 3, as viewed from the side from which the laser beam or the like has been radiated, the second fusion zones are located at opposite end portions of the fusion zone. Thus, an excess stress difference which the first fusion zone fails to absorb is evenly applied to the thick portions of the fusion zone, whereby a stress difference can be more effectively absorbed. Also, the wedge function is more strongly exhibited, whereby movement of the fusion zone can be more reliably restrained. As a result, the effect of preventing separation of the noble metal tip can be further improved.

Configuration 4. A spark plug of the present configuration is characterized in that, in any one of the above configurations 1 to 3, the noble metal tip is joined to at least the ground electrode, and

through radiation of the laser beam or the electron beam from a side toward each of a distal end surface and opposite side surfaces of the ground electrode, the second fusion zone is formed on each of the distal end surface and the opposite side surfaces of the ground electrode.

According to the above configuration 4, at least three second fusion zones are provided corresponding to the distal end surface and the opposite side surfaces of the ground electrode, whereby the effect of absorbing a stress difference or the like effect can be further enhanced.

Configuration 5. A spark plug of the present configuration is characterized in that, in any one of the above configurations 1 to 4, the noble metal tip is joined to at least the ground electrode;

a plurality of the second fusion zones are formed; and

as viewed from a side toward the other end surface of the noble metal tip, the second fusion zones are formed at positions located symmetrically with respect to a center axis of the noble metal tip.

Notably, the concept of the term "symmetrical" encompasses not only the case where the second fusion zones are formed at strictly symmetrical positions with respect to the center axis, but also the case where the second fusion zones are formed at positions slightly deviated from the symmetrical positions. Therefore, for example, as viewed from a side toward the other end surface of the noble metal tip, when the center of the outer surface (the surface irradiated with the laser beam or the like) of one second fusion zone is imaginarily moved to its symmetrical position with respect to the center axis, the center of the outer surface of the other second fusion zone may be deviated slightly (by, e.g., about 0.1 mm) from the moved center.

According to the above configuration 5, since the second fusion zones (thick portions of the fusion zone) are located at symmetrical positions with respect to the center axis of the noble metal tip, the thick portions can evenly absorb a stress difference. Therefore, the fusion zone can more reliably absorb a stress difference, whereby separation resistance of the noble metal tip can be further improved.

Configuration 6. A spark plug of the present configuration is characterized in that, in any one of the above configurations 1 to 5, the noble metal tip is joined to at least the ground electrode;

a plurality of the second fusion zones are formed; and

as viewed from a side toward the other end surface of the noble metal tip, the second fusion zones are formed at positions located symmetrically with respect to a straight line (baseline) which extends along a longitudinal direction of the ground electrode and passes through a center axis of the noble metal tip.

Notably, the concept of the term "symmetrical" encompasses not only the case where the second fusion zones are formed at strictly symmetrical positions with respect to the baseline, but also the case where the second fusion zones are formed at positions slightly deviated from the symmetrical positions. Therefore, for example, as viewed from a side toward the other end surface of the noble metal tip, when the center of the outer surface of one second fusion zone is imaginarily moved to its symmetrical position with respect to the baseline, the center of the outer surface of the other second fusion zone may be deviated slightly (by, e.g., about 0.1 mm) from the moved center.

According to the above configuration 6, since the second fusion zones (thick portions of the fusion zone) are located at symmetrical positions with respect to the baseline, the thick portions can evenly absorb a stress difference, whereby separation resistance of the noble metal tip can be further improved.

Configuration 7. A spark plug of the present configuration is characterized in that, in any one of the above configurations 1 to 5, the noble metal tip is joined to at least the ground electrode;

a plurality of the second fusion zones are formed; and

as viewed from a side toward the other end surface of the noble metal tip, the second fusion zones are formed at positions located symmetrically with respect to a straight line (orthogonal baseline) which extends along a direction orthogonal to a longitudinal direction of the ground electrode and passes through a center axis of the noble metal tip.

Notably, the concept of the term "symmetrical" encompasses not only the case where the second fusion zones are formed at strictly symmetrical positions with respect to the orthogonal baseline, but also the case where the second fusion zones are formed at positions slightly deviated from the symmetrical positions. Therefore, for example, as viewed from a side toward the other end surface of the noble metal tip, when the center of the outer surface of one second fusion zone is imaginarily moved to its symmetrical position with respect to the orthogonal baseline, the center of the outer surface of the other second fusion zone may be deviated slightly (by, e.g., about 0.1 mm) from the moved center.

According to the above configuration 7, the thick portions can evenly absorb a stress difference, whereby separation resistance of the noble metal tip can be further improved.

Configuration 8. A spark plug of the present configuration is characterized in that, in the above configuration 1, the noble metal tip is joined to at least the center electrode;

the first fusion zone is formed along the entire circumference of the noble metal tip;

a plurality of the second fusion zones are formed; and

as viewed from a side toward the other end surface of the noble metal tip, the second fusion zones are formed at positions located symmetrically with respect to a center axis of the noble metal tip.

Notably, the concept of the expression "the second fusion zones are formed at positions located symmetrically with respect to a center axis of the noble metal tip" encompasses the case where "a plurality of the second fusion zones are provided at equal intervals along the circumferential direction of the noble metal tip."

The concept of the term "symmetrical" encompasses not only the case where the second fusion zones are formed at strictly symmetrical positions, but also the case where the second fusion zones are formed at positions slightly deviated from the symmetrical positions. Therefore, when the second fusion zones are formed at strictly symmetrical positions with respect to the center axis, as viewed from a side toward the other end surface of the noble metal tip, an angle of 360°/n (n is the number of the second fusion zones) is formed between a straight line which connects the center axis and the center of the outer surface of one second fusion zone, and a straight line which connects the center axis and the center of the outer surface of the second fusion zone adjacent to the one second fusion zone; however, the second fusion zones may be formed such that the angle deviates slightly (by, e.g., about 10°) from 360°/n.

According to the above configuration 8, since the first fusion zone is formed along the entire circumference of the noble metal tip, the effect of absorbing a stress difference by the first fusion zone can be enhanced. Also, as viewed from a side toward the other end surface of the noble metal tip, since the second fusion zones are formed at symmetrical positions with respect to the center axis of the noble metal tip, thick portions of the fusion zone implemented by the second fusion zones can evenly absorb a stress difference. As a result, coupled with improvement in the effect of absorbing a stress difference by the first fusion zone, the separation of the noble metal tip can be quite effectively prevented.

Configuration 9. A spark plug of the present configuration is characterized in that, in the above configuration 8, assuming that an outer circumferential surface of the fusion zone is equally divided into three segmental regions along a circumferential direction thereof, the second fusion zone exists in each of the three segmental regions.

According to the above configuration 9, when the fusion zone as viewed from a side toward the other end surface of the noble metal tip is equally divided into three divisions about the center axis of the noble metal tip, the second fusion zone exists in each of the three divisions of the fusion zone. Therefore, a stress difference can be more reliably absorbed, whereby separation resistance can be further improved.

Configuration 10. A spark plug of the present configuration is characterized in that, in any one of the above configurations 1 to 9, the first fusion zone has a maximum thickness of 0.3 mm or less along a center axis of the noble metal tip.

According to the above configuration 10, the maximum thickness of the first fusion zone along the center axis of the noble metal tip is specified as 0.3 mm or less; i.e., the first fusion zone is formed very thin. Therefore, the volume of the noble metal tip can be further increased, whereby erosion resistance can be further improved.

Meanwhile, when the first fusion zone is formed thin, deterioration in separation resistance is of concern; however, the concern can be erased through provision of the second fusion zone(s). In other words, the provision of the second fusion zone(s) is particularly effective in the case where the maximum thickness of the first fusion is specified as 0.3 mm or less.

Configuration 11. A spark plug of the present configuration is characterized in that, in any one of the above configurations 1 to 10, a length of an outer surface of the second fusion zone along a perimetrical direction of the noble metal tip is 30% or more of a length of an outer surface of the first fusion zone along the perimetrical direction of the noble metal tip.

Notably, "the outer surface of the first fusion zone and the outer surface of the second fusion zone" are surfaces irradiated with the laser beam or the electron beam. Also, in the case where a plurality of the first fusion zones and a plurality of the second fusion zones are provided, "the length of the outer surface of the first fusion zone and the length of the outer surface of the second fusion zone" mean the total length of the outer surfaces of the first fusion zones along the perimetrical direction of the noble metal tip and the total length of the outer surfaces of the second fusion zones along the perimetrical direction of the noble metal tip.

According to the above configuration 11, the second fusion zone is formed over a relatively wide range of a boundary region between a perimetrical portion of the noble metal tip and the object member (the center electrode or the ground electrode), the boundary region being where a particularly large stress difference arises in association with thermal expansion. Therefore, a stress difference associated with thermal expansion can be more reliably absorbed, whereby separation resistance can be further improved.

Configuration 12. A spark plug of the present configuration is characterized in that, in any one of the above configurations 1 to 10, a length of an outer surface of the second fusion zone along a perimetrical direction of the noble metal tip is 50% or more of a length of an outer surface of the first fusion zone along the perimetrical direction of the noble metal tip.

According to the above configuration 12, a stress difference can be more effectively absorbed, whereby separation resistance can be further improved.

Configuration 13. A spark plug of the present configuration is characterized in that, in any one of the above configurations 1 to 10, a length of an outer surface of the second fusion zone along a perimetrical direction of the noble metal tip is 70% or more of a length of an outer surface of the first fusion zone along the perimetrical direction of the noble metal tip.

According to the above configuration 13, a stress difference can be far more effectively absorbed, whereby separation resistance can be far more greatly improved.

Configuration 14. A spark plug of the present configuration is characterized in that, in any one of the above configurations 1 to 13, as viewed on a plane of projection which is orthogonal to a center axis of the noble metal tip and on which the noble metal tip and the fusion zone are projected along the center axis,

a projected overlap region of the noble metal tip and the fusion zone accounts for 50% or more of a projected region of the noble metal tip.

According to the above configuration 14, half or more of one end surface (bottom surface) of the noble metal tip is joined to the object member (the ground electrode or the center electrode); thus, a sufficiently wide fusion zone intervenes between the object member and the one end surface of the noble metal tip. Therefore, sufficient strength of joining the noble metal tip to the object member can be ensured, so that the actions and effects of the above configuration 1, etc., are more reliably yielded.

Configuration 15. A spark plug of the present configuration comprises:

a rodlike center electrode extending in a direction of an axis;

a tubular insulator provided around the center electrode;

a tubular metallic shell provided around the insulator;

a ground electrode whose proximal end is welded to the metallic shell and whose distal end faces the center electrode; and

a columnar noble metal tip formed from a noble metal alloy and provided on at least one object member of the center electrode and the ground electrode.

The spark plug is characterized in that:

one end surface of the noble metal tip is joined to the object member via a fusion zone which is formed by radiating a laser beam or an electron beam from a side toward a side surface of the noble metal tip in such a manner as to intersect with a boundary between the noble metal tip and the object member, and

the fusion zone comprises a plurality of segmental fusion zones formed across the boundary between the object member and the one end surface of the noble metal tip.

According to the above configuration 15, the fusion zone comprises a plurality of the segmental fusion zones formed across the boundary between the object member (the center electrode or the ground electrode) and the one end surface of the noble metal tip. That is, a plurality of the segmental fusion zones penetrate into both of the object member and the noble metal tip. Therefore, the segmental fusion zones function as, so to speak, wedges, whereby there can be restrained movement of the noble metal tip in relation to the object member associated with a stress difference which arises between the noble metal tip and the object member. As a result, strength of joining the noble metal tip to the object member can be improved, whereby excellent separation resistance can be implemented.

Configuration 16. A spark plug of the present configuration is characterized in that, in the above configuration 15, the noble metal tip is joined to at least an inner side surface of the ground electrode, and the fusion zone is formed through radiation of the laser beam or the electron beam from a side toward at least one of a distal end surface and opposite side surfaces of the ground electrode, and

as viewed from the side from which the laser beam or the electron beam has been radiated, a portion of an outer surface of the fusion zone located on a boundary between the noble metal tip and the ground electrode has a length which is 30% or more of a length of the boundary.

According to the above configuration 16, the segmental fusion zones are formed over a relatively wide range of a boundary region between the ground electrode and a perimetrical portion of the noble metal tip, the boundary region being where a particularly large stress difference arises. Therefore, the segmental fusion zones can more effectively exhibit the wedge function, whereby separation resistance can be further improved.

Configuration 17. A spark plug of the present configuration is characterized in that, in the above configuration 15, the noble metal tip is joined to at least an inner side surface of the ground electrode, and the fusion zone is formed through radiation of the laser beam or the electron beam from a side toward at least one of a distal end surface and opposite side surfaces of the ground electrode, and

as viewed from the side from which the laser beam or the electron beam has been radiated, a portion of an outer surface of the fusion zone located on a boundary between the noble metal tip and the ground electrode has a length which is 50% or more of a length of the boundary.

According to the above configuration 17, the segmental fusion zones can far more effectively exhibit the wedge function, whereby separation resistance can be far more greatly improved.

Configuration 18. A spark plug of the present configuration is characterized in that, in any one of the above configurations 15 to 17, the noble metal tip is joined to at least the ground electrode, and through radiation of the laser beam or the electron beam from a side toward each of a distal end surface and opposite side surfaces of the ground electrode, the segmental fusion zones are formed on the distal end surface and the opposite side surfaces of the ground electrode.

According to the above configuration 18, since the segmental fusion zones are provided corresponding to the distal end surface and the opposite side surfaces of the ground electrode, the segmental fusion zones exhibit the wedge function in a wide range of the boundary surface between the noble metal tip and the ground electrode. As a result, strength of joining the noble metal tip can be further enhanced, whereby quite excellent separation resistance can be implemented.

Configuration 19. A spark plug of the present configuration is characterized in that, in any one of the above configurations 15 to 18, the noble metal tip is joined to at least the ground electrode, and

as viewed from a side toward the other end surface of the noble metal tip, the segmental fusion zones are formed at positions located symmetrically with respect to a center axis of the noble metal tip.

Notably, the concept of the expression "the segmental fusion zones are formed at positions located symmetrically with respect to the center axis of the noble metal tip" encompasses the case where "a plurality of the fusion zones are provided at equal intervals along a perimetrical direction."

Also, the concept of the term "symmetrical" encompasses not only the case where the segmental fusion zones are formed at strictly symmetrical positions with respect to the center axis, but also the case where the segmental fusion zones are formed at positions slightly deviated from the symmetrical positions. Therefore, for example, as viewed from a side toward the other end surface of the noble metal tip, when the center of the outer surface (the surface irradiated with the laser beam or the like) of one segmental fusion zone is imaginarily moved to its symmetrical position with respect to the center axis, the center of the outer surface of the other segmental fusion zone may be deviated slightly (by, e.g., about 0.1 mm) from the moved center.

According to the above configuration 19, as viewed from a side toward the other end surface of the noble metal tip, the segmental fusion zones are formed at symmetrical positions with respect to the center axis of the noble metal tip. That is, the segmental fusion zones are disposed in a well balanced manner on the boundary surface between the noble metal tip and the ground electrode. Therefore, the segmental fusion zones more effectively exhibit the wedge function, whereby separation resistance can be further enhanced.

Configuration 20. A spark plug of the present configuration is characterized in that, in any one of the above configurations 15 to 19, the noble metal tip is joined to at least the ground electrode, and

as viewed from a side toward the other end surface of the noble metal tip, the segmental fusion zones are formed at positions located symmetrically with respect to a straight line which extends along a longitudinal direction of the ground electrode and passes through a center axis of the noble metal tip.

Notably, the concept of the term "symmetrical" encompasses not only the case where the segmental fusion zones are formed at strictly symmetrical positions with respect to the straight line which extends along the longitudinal direction of the ground electrode and passes through the center axis of the noble metal tip, but also the case where the segmental fusion zones are formed at positions slightly deviated from the symmetrical positions. Therefore, for example, as viewed from a side toward the other end surface of the noble metal tip, when the center of the outer surface of one segmental fusion zone is imaginarily moved to its symmetrical position with respect to the straight line, the center of the outer surface of the other segmental fusion zone may be deviated slightly (by, e.g., about 0.1 mm) from the moved center.

According to the above configuration 20, similar to the above configuration 19, the segmental fusion zones are disposed in a well balanced manner on the boundary surface between the noble metal tip and the ground electrode. Therefore, the segmental fusion zones more effectively exhibit the wedge function, whereby separation resistance can be further enhanced.

Configuration 21. A spark plug of the present configuration is characterized in that, in any one of the above configurations 15 to 19, the noble metal tip is joined to at least the ground electrode, and

as viewed from a side toward the other end surface of the noble metal tip, the segmental fusion zones are formed at positions located symmetrically with respect to a straight line which extends along a direction orthogonal to a longitudinal direction of the ground electrode and passes through a center axis of the noble metal tip.

Notably, the concept of the term "symmetrical" encompasses not only the case where the segmental fusion zones are formed at strictly symmetrical positions with respect to the straight line which extends along a direction orthogonal to the longitudinal direction of the ground electrode and passes through the center axis of the noble metal tip, but also the case where the segmental fusion zones are formed at positions slightly deviated from the symmetrical positions. Therefore, for example, as viewed from a side toward the other end surface of the noble metal tip, when the center of the outer surface of one segmental fusion zone is imaginarily moved to its symmetrical position with respect to the straight line, the center of the outer surface of the other segmental fusion zone may be deviated slightly (by, e.g., about 0.1 mm) from the moved center.

According to the above configuration 21, since the segmental fusion zones are disposed in a well balanced manner on the boundary surface between the noble metal tip and the ground electrode, the segmental fusion zones more effectively exhibit the wedge function, whereby separation resistance can be further improved.

Configuration 22. A spark plug of the present configuration is characterized in that, in any one of the above configurations 15 to 21, the noble metal tip is joined to at least the center electrode), and

a portion of an outer surface of the fusion zone located on a boundary between the noble metal tip and the center electrode has a length which is 30% or more of a length of the boundary.

According to the above configuration 22, the segmental fusion zones are formed over a relatively wide range of a boundary region between the center electrode and a circumferential portion of the noble metal tip, the boundary region being where a particularly large stress difference arises. Therefore, the segmental fusion zones can more effectively exhibit the wedge function, whereby separation resistance can be further improved.

Configuration 23. A spark plug of the present configuration is characterized in that, in any one of the above configurations 15 to 21, the noble metal tip is joined to at least the center electrode, and a portion of an outer surface of the fusion zone located on a boundary between the noble metal tip and the center electrode has a length which is 50% or more of a length of the boundary.

According to the above configuration 23, the segmental fusion zones can far more effectively exhibit the wedge function, whereby separation resistance can be far more greatly improved.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** Partially cutaway front view showing the configuration of a spark plug.

FIG. **2** Partially cutaway, enlarged, front view showing the configuration of a forward end portion of the spark plug.

FIG. **3** Fragmentary, enlarged, side view showing the configuration of a fusion zone.

FIG. **4** Enlarged, schematic, side view for explaining the method of measuring the length of the outer surfaces of second fusion zones.

FIG. **5** Projection view showing a plane of projection on which a noble metal tip and the fusion zone are projected.

FIG. **6** Fragmentary, enlarged, side view showing another example of the fusion zone.

FIG. **7** Fragmentary, enlarged, side view showing a further example of the fusion zone.

FIG. **8** Fragmentary, enlarged, side view showing a still further example of the fusion zone.

FIG. **9** Fragmentary, enlarged, side view showing yet another example of the fusion zone.

FIG. **10** Fragmentary, enlarged, plan view showing another example of the fusion zone.

FIG. **11** Fragmentary, enlarged, plan view showing a further example of the fusion zone.

FIG. **12** Fragmentary, enlarged, plan view showing a still further example of the fusion zone.

FIG. **13** Fragmentary, enlarged, plan view showing yet another example of the fusion zone.

FIG. **14** Fragmentary, enlarged, plan view showing another example of a second fusion zone.

FIG. **15** Fragmentary, enlarged, plan view showing a further example of the second fusion zone.

FIG. **16** Fragmentary, enlarged, plan view showing a still further example of the second fusion zone.

FIG. **17** Fragmentary, enlarged, side view showing yet another example of the second fusion zone.

FIG. **18** Fragmentary, enlarged, side view showing another example of the second fusion zone.

FIG. **19** Partially cutaway, enlarged, front view showing the configuration of a forward end portion of a spark plug according to a second embodiment.

FIG. **20** Fragmentary, enlarged, front view showing the configuration of a fusion zone, etc., in the second embodiment.

FIG. **21** Fragmentary, enlarged, plan view showing the configuration of a second fusion zone.

FIG. **22** Fragmentary, enlarged, plan view showing another example of the second fusion zone.

FIG. **23** Fragmentary, enlarged, plan view showing a further example of the second fusion zone.

FIG. **24** Fragmentary, enlarged, plan view showing a still further example of the second fusion zone.

FIG. **25** Fragmentary, enlarged, plan view showing yet another example of the second fusion zone.

FIG. **26** Fragmentary, enlarged, plan view showing another example of the second fusion zone.

FIG. **27** Fragmentary, enlarged, plan view showing a further example of the second fusion zone.

FIG. **28** Fragmentary, enlarged, plan view showing a still further example of the second fusion zone.

FIG. **29** Fragmentary, enlarged, front view showing yet another example of the second fusion zone.

FIG. **30** Fragmentary, enlarged, front view showing another example of the second fusion zone.

FIG. **31** Fragmentary, enlarged, side view showing the configuration of a fusion zone in a third embodiment.

FIG. **32** Fragmentary, enlarged, plan view showing the configuration of the fusion zone in the third embodiment.

FIG. **33** Fragmentary, enlarged, plan view showing another example of the fusion zone.

FIG. **34** Fragmentary, enlarged, plan view showing a further example of the fusion zone.

FIG. **35** Fragmentary, enlarged, plan view showing a still further example of the fusion zone.

FIG. **36** Fragmentary, enlarged, side view showing yet another example of the fusion zone.

FIG. **37** Fragmentary, enlarged, front view showing the configuration of a fusion zone in a fourth embodiment.

FIG. **38** Sectional view taken along line J-J of FIG. **37**.

FIG. **39** Development view of outer circumferential surfaces of a center electrode, a fusion zone, etc.

FIG. **40** Fragmentary, enlarged, front view showing another example of the second fusion zone.

FIG. **41** Sectional view taken along line J-J of FIG. **40**.

FIG. **42** Development view of outer circumferential surfaces of the center electrode, the fusion zone, etc.

FIGS. **43**(*a*) and **43**(*b*) Development views of outer circumferential surfaces of the center electrode, the fusion zone, etc., showing a further example of the fusion zone.

FIG. **44**(*a*) Development view of outer circumferential surfaces of the center electrode, the fusion zone, etc., showing a still further example of the fusion zone.

FIG. **44**(*b*) Sectional view showing the fusion zone as viewed at a radially inner position.

FIG. **45** Partially cutaway, enlarged, front view showing the configuration of a forward end portion of a spark plug according to another embodiment.

FIG. **46** Fragmentary, enlarged, side view showing the configuration of the fusion zone in a further embodiment.

FIG. **47** Fragmentary, enlarged, side view showing the configuration of the fusion zone in a still further embodiment.

FIG. **48** Fragmentary, enlarged, side view showing the configuration of the fusion zone in yet another embodiment.

FIG. **49** Partially cutaway, enlarged, front view showing the configuration of a forward end portion of a spark plug according to a further embodiment.

MODES FOR CARRYING OUT THE INVENTION

Embodiments of the present invention will next be described with reference to the drawings.

First Embodiment

FIG. **1** is a partially cutaway front view showing a spark plug **1**. In the following description, the direction of an axis CL**1** of the spark plug **1** in FIG. **1** is referred to as the vertical direction, and the lower side of the spark plug **1** in FIG. **1** is referred to as the forward side of the spark plug **1**, and the upper side as the rear side of the spark plug **1**.

The spark plug **1** includes a ceramic insulator **2**, which corresponds to the tubular insulator in the present invention, and a tubular metallic shell **3**, which holds the ceramic insulator **2**.

The ceramic insulator **2** is formed from alumina or the like by firing, as well known in the art. The ceramic insulator **2** externally includes a rear trunk portion **10** formed on the rear side; a large-diameter portion **11**, which is located forward of the rear trunk portion **10** and projects radially outward; an intermediate trunk portion **12**, which is located forward of the large-diameter portion **11** and is smaller in diameter than the large-diameter portion **11**; and a leg portion **13**, which is located forward of the intermediate trunk portion **12** and is smaller in diameter than the intermediate trunk portion **12**. Additionally, the large-diameter portion **11**, the intermediate trunk portion **12**, and most of the leg portion **13** of the ceramic insulator **2** are accommodated in the metallic shell **3**. A tapered, stepped portion **14** is formed at a connection portion between the leg portion **13** and the intermediate trunk portion **12**, and the ceramic insulator **2** is seated on the metallic shell **3** via the stepped portion **14**.

Furthermore, the ceramic insulator **2** has an axial bore **4** extending therethrough along the axis CL**1**, and a center electrode **5** is fixedly inserted into a forward end portion of the axial bore **4**. The center electrode **5** includes an inner layer **5**A of copper or a copper alloy, which has excellent thermal conductivity, and an outer layer **5**B of an Ni alloy which contains nickel (Ni) as a main component. Additionally, the center electrode **5** assumes a rodlike (circular columnar) shape as a whole; has the flat forward end surface; and projects from the forward end of the ceramic insulator **2**. Also, a circular columnar noble metal member **31** of a predetermined noble metal alloy (e.g., a platinum alloy or an iridium alloy) is provided at a forward end portion of the center electrode **5**.

Also, a terminal electrode **6** is fixedly inserted into the rear side of the axial bore **4** in such a manner as to project from the rear end of the ceramic insulator **2**.

Furthermore, a circular columnar resistor **7** is disposed within the axial bore **4** between the center electrode **5** and the terminal electrode **6**. Opposite end portions of the resistor **7** are electrically connected to the center electrode **5** and the terminal electrode **6** via electrically conductive glass seal layers **8** and **9**, respectively.

Additionally, the metallic shell **3** is formed into a tubular shape from a low-carbon steel or the like and has a threaded portion (externally threaded portion) **15** on its outer circumferential surface, and the threaded portion **15** is adapted to mount the spark plug **1** into a mounting hole of a combustion apparatus (e.g., an internal combustion engine or a fuel cell reformer). The metallic shell **3** has a seat portion **16** formed on its outer circumferential surface and located rearward of the threaded portion **15**. A ring-like gasket **18** is fitted to a screw neck **17** located at the rear end of the threaded portion **15**. Furthermore, the metallic shell **3** also has a tool engagement portion **19** provided near its rear end. The tool engagement portion **19** has a hexagonal cross section and allows a tool such as a wrench to be engaged therewith when the metallic shell **3** is to be mounted to the combustion apparatus. The metallic shell **3** also has a crimp portion **20** provided at its rear end portion and adapted to hold the ceramic insulator **2**.

The metallic shell **3** has a tapered, stepped portion **21** provided on its inner circumferential surface and adapted to allow the ceramic insulator **2** to be seated thereon. The ceramic insulator **2** is inserted forward into the metallic shell **3** from the rear end of the metallic shell **3**. In a state in which the stepped portion **14** of the ceramic insulator **2** butts against the stepped portion **21** of the metallic shell **3**, a rear-end opening portion of the metallic shell **3** is crimped radially inward; i.e., the crimp portion **20** is formed, whereby the ceramic insulator **2** is fixed to the metallic shell **3**. An annular sheet packing **22** intervenes between the stepped portions **14** and **21** of the ceramic insulator **2** and the metallic shell **3**, respectively. This retains gastightness of a combustion chamber and prevents leakage of fuel gas to the exterior of the spark plug **1** through a clearance between the inner circumferential surface of the metallic shell **3** and the leg portion **13** of the ceramic insulator **2**, the leg portion **13** being exposed to the combustion chamber.

Furthermore, in order to ensure gastightness which is established by crimping, annular ring members **23** and **24** intervene between the metallic shell **3** and the ceramic insulator **2** in a region near the rear end of the metallic shell **3**, and a space between the ring members **23** and **24** is filled with a powder of talc **25**. That is, the metallic shell **3** holds the ceramic insulator **2** via the sheet packing **22**, the ring members **23** and **24**, and the talc **25**.

As shown in FIG. **2**, a ground electrode **27** is provided at a forward end portion **26** of the metallic shell **3**. The ground electrode **27** is welded at its proximal end portion to the metallic shell **3** and is bent at its intermediate portion such that its distal end portion faces a forward end portion (the noble metal member **31**) of the center electrode **5**. The ground electrode **27** is formed from an Ni alloy which contains Ni as a main component (e.g., an alloy which contains Ni as a main component, as well as at least one of silicon, aluminum, and rare earth elements).

Furthermore, one end surface of a noble metal tip **32** resembling in shape to a square column (square parallelepiped) is joined to a surface (inner side surface) **27**I of the ground electrode **27** located on a side toward the center electrode **5** at a portion which faces the forward end surface of the noble metal member **31** (in the present embodiment, the ground electrode **27** corresponds to the “object member” in the present invention). The noble metal tip **32** is formed from a predetermined noble metal alloy (for example, a noble metal alloy which contains at least one of iridium, platinum, rhodium, ruthenium, palladium, and rhenium). In the present embodiment, in order to keep a lid on manufacturing cost, the noble metal tip **32** is formed relatively thin (e.g., 0.2 mm to 0.6 mm), whereas, in order to improve erosion resistance, the other end surface (discharge surface) **32**F of the noble metal tip **32** which faces the noble metal member **31** has a relatively large area (e.g., 0.6 mm^2 or more).

Additionally, a spark discharge gap **33** is formed between the noble metal member **31** and the other end surface **32**F of the noble metal tip **32**, and spark discharges are performed across the spark discharge gap **33** along the direction of the axis CL**1**.

Additionally, the noble metal tip **32** is joined at its one end surface to the ground electrode **27** via a fusion zone **35** formed through radiation of a laser beam or an electron beam from a side toward its side surface. The fusion zone **35** is formed through fusion of a metal used to form the noble metal tip **32** and a metal used to form the ground electrode **27** and includes, as shown in FIG. **3** (FIG. **3** is an enlarged side view as viewed from a side toward a distal end surface **27**F of the ground electrode **27**), a first fusion zone **351** and a second fusion zone **352**.

The first fusion zone **351** is formed by continuously radiating a laser beam or an electron beam from a side toward the distal end surface **27**F of the ground electrode **27** to the boundary region between the ground electrode **27** and the one end surface of the noble metal tip **32** along the perimetrical direction of the noble metal tip **32**. The first fusion zone **351** has a flat shape extending substantially along the other end surface **32**F of the noble metal tip **32**. In the present embodiment, as viewed from the side from which the laser beam or the like has been radiated to the surface (the distal end surface **27**F) of the ground electrode **27**, the first fusion zone **351** is formed along the entire width of the noble metal tip **32**.

Also, a plurality of the second fusion zones **352** are provided, and the second fusion zones **352** are formed in such a manner as to intersect with (in the present embodiment, to be substantially orthogonal to) the first fusion zone **351**. The second fusion zones **352** are formed by radiating the laser beam or the like in such a manner as to intersect with (in the present embodiment, to be substantially orthogonal to) the first fusion zone **351**, from the side from which the laser beam or the like has been radiated in forming the first fusion zone **351** (i.e., from the side toward the distal end surface **27**F of the ground electrode **27**). In the present embodiment, regarding at least the side of the fusion zone **35** which has been irradiated with the laser beam or the like (e.g., between a region irradiated with the laser beam or the like and a center axis CL**2** of the noble metal tip **32**), the thickness of the second fusion zones **352** along the center axis CL**2** of the noble metal tip **32** is greater than the thickness of the first fusion zone **351** along the center axis CL**2**.

Also, in the present embodiment, the second fusion zones **352** are provided at the following positions. When the noble metal tip **32** and the fusion zone **35** are viewed from the side from which the laser beam or the like has been radiated to the surface (the distal end surface **27**F) of the ground electrode **27**, a portion of the fusion zone **35** located between the ground electrode **27** and the noble metal tip **32** is equally divided into three segmental regions along the width direction of the noble metal tip **32**. At this time, in each of the three segmental regions, the second fusion zone **352** is provided in such a manner as to be in contact with the first fusion zone **351**.

Additionally, the length of the outer surfaces of the second fusion zones **352** (L**21**+L**22**+L**23**+L**24**+L**25**) along the perimetrical direction (width direction) of the noble metal tip **32** is specified as 30% or more of a length L**1** of the first fusion zone **351** along the perimetrical direction of the noble metal tip **32**.

The length of the outer surfaces of the second fusion zones **352** along the perimetrical direction of the noble metal tip **32** can be measured as follows. As shown in FIG. **4**, boundary lines BL**1** between the first fusion zone **351** and the noble metal tip **32** are connected by imaginary straight lines VL**1**; boundary lines BL**1** between the first fusion zone **351** and the ground electrode **27** are connected by the imaginary straight lines VL**1**; and a surface sandwiched between a group of the boundary lines BL**1** and the imaginary straight lines VL**1** on one side and a group of the boundary lines BL**1** and the imaginary straight lines VL**1** on the other side is specified as the outer surface of the first fusion zone **351**. Meanwhile, a boundary line BL**2** between the second fusion zone **352** and the noble metal tip **32** and the boundary line BL**2** between the second fusion zone **352** and the ground electrode **27** are connected by imaginary straight lines VL**2**, and a surface surrounded by the boundary lines BL**2** and the imaginary straight lines VL**2** is specified as the outer surface of the second fusion zone **352**. Next, a region where the specified outer surface of the first fusion zone **351** and the specified outer surface of the second fusion zone **352** overlap each other is specified as an overlap region. There is drawn a straight line L**1** which passes through the center of the outer surface of the first fusion zone **352** with respect to the direction along the center axis CL**2**. The total length of those line segments of the straight line L**1** which pass through the respective overlap regions is measured, whereby there can be obtained the length of the outer surfaces of the second fusion zones **352** along the perimetrical direction of the noble metal tip **32**.

Furthermore, in the present embodiment, as shown in FIG. **5** (the arrow in FIG. **5** indicates the direction of radiation of the laser beam or the like), as viewed on a plane of projection PS which is orthogonal to the center axis CL**2** and on which the noble metal tip **32** and the fusion zone **35** are projected along the center axis CL**2** of the noble metal tip **32**, a projected overlap region (the hatched region in FIG. **5**) of the noble metal tip **32** and the fusion zone **35** accounts for 50% or more (in the present embodiment, 100%) of a projected region of the noble metal tip **32**. That is, half or more of one end surface (in the present embodiment, the entire one end surface) of the noble metal tip **32** is joined to the ground electrode **27** via the fusion zone **35**.

Meanwhile, the noble metal tip **32** is relatively thin as mentioned above, and, in view of sufficiently reducing the amount of fusion of the noble metal tip **32** in forming the fusion zone **35** so as to ensure a sufficient volume of the noble metal tip **32**, the first fusion zone **351** is formed relatively thin. In the present embodiment, the maximum thickness T_{MAX} of the first fusion zone **351** along the center axis CL**2** of the noble metal tip **32** is specified as 0.3 mm or less (see FIG. **3**).

The number of the second fusion zones **352** is not particularly limited; for example, the number of the second fusion zones **352** may be changed as shown in FIGS. **6** and **7**. Also, no particular limitation is imposed on the positions of the second fusion zones **352** in relation to the first fusion zone **351** (the noble metal tip **32**). For example, as shown in FIG. **8**, the first fusion zone **351** and the second fusion zone **352** may be in contact with each other only in the center one of the three segmental regions. Alternatively, as shown in FIG. **9**, the first fusion zone **351** and the second fusion zone **352** may be in contact with each other only in opposite end ones of the three segmental regions.

Furthermore, a side from which the laser beam or the like is radiated is not limited to the side toward the distal end surface **27**F of the ground electrode **27**. As shown in FIG. **10** (the arrows in FIGS. **10** to **13** indicate the direction of radiation of the laser beam or the like), a fusion zone **36** may be formed through radiation of the laser beam or the like from a side toward one of side surfaces **27S1** and **27S2** adjacent to both of the distal end surface **27**F and the inner side surface **27**I of the ground electrode **27**. Also, as shown in FIG. **11**, a fusion zone **37** may be formed through radiation of the laser beam or the like from both sides toward the opposite side surfaces **27S1** and **27S2**; alternatively, as shown in FIG. **12**, a fusion zone **38** may be formed through radiation of the laser beam or the like from a side toward one of the opposite side surfaces **27S1** and **27S2** and from a side toward the distal end surface **27**F. Furthermore, as shown in FIG. **13**, a fusion zone **39** may be formed through radiation of the laser beam or the like from the side toward the distal end surface **27**F and from the sides toward the opposite side surfaces **27S1** and **27S2**.

Additionally, as shown in FIG. **14** (in FIGS. **14** to **16**, the first fusion zone is not shown), when the noble metal tip **32** and second fusion zones **402** are viewed from a side toward the other end surface **32**F of the noble metal tip **32**, the second fusion zones **402** may exist at positions located symmetrically with respect to the center axis CL**2** of the noble metal tip **32**.

Furthermore, as shown in FIG. **15**, as viewed from the side toward the other end surface **32**F of the noble metal tip **32**, second fusion zones **412** may be formed at positions located symmetrically with respect to a straight line (baseline) KL**1** which extends along the longitudinal direction of the ground electrode **27** and passes through the center axis CL**2** of the noble metal tip **32**. Also, as shown in FIG. **16**, as viewed from the side toward the other end surface **32**F of the noble metal tip **32**, second fusion zones **422** may be formed at positions located symmetrically with respect to a straight line (baseline) KL**2** which extends along a direction orthogonal to the longitudinal direction of the ground electrode **27** and passes through the center axis CL**2** of the noble metal tip **32**.

Additionally, instead of forming the second fusion zones **352** orthogonally to the first fusion zone **351**, for example, as shown in FIG. **17**, second fusion zones **432** may be formed in such a manner as to obliquely intersecting with a first fusion zone **431**.

Furthermore, the second fusion zone may be formed by continuously radiating the laser beam or the like; for example, as shown in FIG. **18** (the dotted line in FIG. **18** indicates a moving path of the position of radiation of the laser beam or the like in forming a second fusion zone **442**), the second fusion zone **442** may be wavily formed by wavily radiating the laser beam or the like.

Next, a method of manufacturing the spark plug **1** configured as mentioned above is described. First, the metallic shell **3** is formed beforehand. Specifically, a circular columnar metal material is subjected to cold forging or the like for forming a general shape and a through hole. Subsequently, machining is conducted so as to adjust the outline, thereby yielding a metallic-shell intermediate.

Then, the ground electrode **27** having the form of a straight rod and formed from an Ni alloy is resistance-welded to the forward end surface of the metallic-shell intermediate. The resistance welding is accompanied by formation of so-called "welding droop." After the "welding droop" are removed, the threaded portion **15** is formed in a predetermined region of the metallic-shell intermediate by rolling. Thus, the metallic shell **3** to which the ground electrode **27** is welded is obtained. The metallic shell **3** to which the ground electrode **27** is welded is subjected to galvanization or nickel plating. In order to enhance corrosion resistance, the plated surface may be further subjected to chromate treatment.

Separately from preparation of the metallic shell **3**, the ceramic insulator **2** is formed. For example, a forming material of granular substance is prepared by use of a material powder which contains alumina in a predominant amount, a binder, etc. By use of the prepared forming material of granular substance, a tubular green compact is formed by rubber press forming. The thus-formed green compact is subjected to grinding for shaping. The shaped green compact is placed in a kiln, followed by firing for forming the ceramic insulator **2**.

Also, separately from preparation of the metallic shell **3** and the ceramic insulator **2**, the center electrode **5** is formed. Specifically, an Ni alloy prepared such that a copper alloy or the like is disposed in a central portion thereof for the purpose of enhancing heat radiation is subjected to forging, thereby forming the center electrode **5**. Next, the noble metal member **31** made of a noble metal alloy is joined to a forward end portion of the center electrode **5** by laser welding or the like.

Next, the ceramic insulator **2** and the center electrode **5**, which are formed as mentioned above, the resistor **7**, and the terminal electrode **6** are fixed in a sealed condition by means of the glass seal layers **8** and **9**. In order to form the glass seal layers **8** and **9**, generally, a mixture of borosilicate glass and a metal powder is prepared, and the prepared mixture is charged into the axial hole **4** of the ceramic insulator **2** such that the resistor **7** is sandwiched therebetween. Subsequently, the resultant assembly is heated in a kiln while the charged mixture is pressed from the rear by the terminal electrode **6**, thereby being fired and fixed. At this time, a glaze layer may be simultaneously fired on the surface of the rear trunk portion **10** of the ceramic insulator **2**; alternatively, the glaze layer may be formed beforehand.

Subsequently, the ceramic insulator **2** having the center electrode **5** and the terminal electrode **6**, and the metallic shell **3** having the ground electrode **27**, which are respectively formed as mentioned above, are fixed together. More specifically, in a state in which the ceramic insulator **2** is inserted into the metallic shell **3**, a relatively thin-walled rear-end opening portion of the metallic shell **3** is crimped radially inward; i.e., the above-mentioned crimp portion **20** is formed, thereby fixing the ceramic insulator **2** and the metallic shell **3** together.

Next, the noble metal tip **32** is joined to a distal end portion of the ground electrode **27**. Specifically, in a state in which the noble metal tip **32** is supported by a predetermined pressing pin, a high-energy laser beam such as a fiber laser beam or an electron beam, is radiated to a boundary region between the ground electrode **27** and the noble metal tip **32** from a side toward the distal end surface **27**F of the ground electrode **27**, while the position of radiation of laser is moved along the perimetrical direction (width direction) of the noble metal tip **32**. By this procedure, the first fusion zone **351** is formed. In forming the first fusion zone **351**, the direction of radiation of the high-energy laser beam is set parallel to the other end surface **32**F of the noble metal tip **32**. Also, conditions of radiation of the laser beam or the like are set such that, while the first fusion zone **351** is being formed in the entire region between the noble metal tip **32** and the ground electrode **27**, the formed first fusion zone **351** has a maximum thickness T_{MAX} of 0.3 mm or less. Specifically, since the thickness of the first fusion zone **351** relatively increases by reducing the working speed, and the thickness of the first fusion zone **351** relatively reduces by increasing the working speed, while output energy is set relatively large, the working speed is set relatively high. Also, the spot diameter of the fiber laser beam is set to a sufficiently small value of five hundredths mm or less. By virtue of this, the first fusion zone **351** is formed sufficiently wide and relatively thin.

Next, the high-energy beam is radiated from the side (the side toward the distal end surface **27**F of the ground electrode **27**) from which the high-energy laser beam has been radiated in forming the first fusion zone **351**, while the position of radiation of laser is moved along the direction of the center axis CL**2** so as to intersect with the formed first fusion zone **351**. This radiation of the laser beam is performed intermittently along the perimetrical direction (width direction) of the noble metal tip **32**, whereby a plurality of the second fusion zones **352** are formed. As a result, the fusion zone **35** composed of the first fusion zone **351** and the second fusion zones **352** is formed, whereby the noble metal tip **32** is joined to the ground electrode **27**. In forming the second fusion zones **352**, in order to enhance working accuracy, a galvano scanner may be used.

In forming the fusion zone **35**, conditions of radiation of the high-energy laser beam (e.g., output and radiation time of the laser beam or the like) may be modified according to the diameter of the noble metal tip **32**, material used to form the noble metal tip **32**, etc.

After the noble metal tip **32** is joined, a substantially middle portion of the ground electrode **27** is bent toward the center electrode **5**, and the magnitude of the spark discharge gap **33** between the noble metal member **31** and the noble metal tip **32** is adjusted, thereby yielding the spark plug **1** described above.

As described above in detail, according to the present embodiment, by virtue of the presence of the second fusion zones **352**, at least portions of the fusion zone **35** are thicker than the first fusion zone **351**. Therefore, the thick portions, which are superior to the first fusion zone **351** in the capability of absorbing a stress difference, can effectively absorb an excess stress difference between the noble metal tip **32** and the ground electrode **27** associated with thermal expansion which the first fusion zone **351** has failed to absorb.

Furthermore, the provision of the second fusion zones **352** renders the boundary surface between the fusion zone **35** and the noble metal tip **32** and the boundary surface between the fusion zone **35** and the ground electrode **27** at least partially protrusive. Therefore, the protrusions function as, so to speak, wedges, whereby movement of the fusion zone **35** in relation to the ground electrode **27** or the like along the boundary surface can be more reliably restrained.

Also, according to the present embodiment, as compared with the case where the first fusion zone **351** is merely rendered thick, the volume of the fusion zone **35** can be sufficiently small. Thus, a portion of the noble metal tip **32** which fuses in the joining process can be reduced, whereby there can be more reliably prevented the exposure of the fusion zone **35** to the spark discharge gap **33** and a situation in which the noble metal tip **32** becomes excessively thin.

As mentioned above, according to the present embodiment, while the effect of improving erosion resistance through provision of the noble metal tip **32** is sufficiently exhibited, the effect of effectively absorbing a stress difference and the effect of preventing movement of the fusion zone **35** through provision of the second fusion zone **352** can synergize, whereby the separation of the noble metal tip **32** can be quite effectively prevented.

Also, as viewed from the side from which the laser beam or the like is radiated, the first fusion zone **351** is formed along the entire width of the noble metal tip **32**, and, assuming that the fusion zone **35** is divided into three segmental regions along its perimetrical direction (width direction), the first fusion zone **351** and the second fusion zone **352** are in contact with each other in each of the three segmental regions. Therefore, the effect of absorbing a stress difference by the first fusion zone **351** is enhanced, and the stress difference is evenly applied to the thick portions (the second fusion zones **352**) of the fusion zone **35**. As a result, the fusion zone **35** can more effectively absorb a stress difference, and the separation of the noble metal tip **32** can be quite effectively prevented.

Furthermore, according to the present embodiment, the length of the outer surfaces of the second fusion zones **352** along the perimetrical direction of the noble metal tip **32** is 30% or more of the length of the outer surface of the first fusion zone **351** along the perimetrical direction of the noble metal tip **32**. That is, the second fusion zones **352** are formed over a relatively wide range of a boundary region between a perimetrical portion of the noble metal tip **32** and the ground electrode **27**, the boundary region being where a particularly large stress difference arises in association with thermal expansion. Therefore, a stress difference associated with thermal expansion can be more reliably absorbed, whereby separation resistance can be further improved.

Particularly, in the case where, as in the case of the present embodiment, the first fusion zone **351** is thin such that the maximum thickness T_{MAX} is 0.3 mm or less, and thus encounters difficulty in absorbing a stress difference by the first fusion zone **351**, with resultant involvement of further concern over the separation of the noble metal tip **32**, the provision of the second fusion zones **352** is effective.

Second Embodiment

Next, the second embodiment will be described, centering on points of difference from the first embodiment described above. As shown in FIG. **19**, a spark plug **41** according to the second embodiment is such that a noble metal tip **42** is joined to a forward end portion of the center electrode **5** via a fusion zone **45** formed through radiation of a laser beam or an electron beam (i.e., in the second embodiment, the center electrode **5** is an "object member"). Meanwhile, the ground electrode **27** does not have a noble metal tip; thus, a spark discharge gap **43** is formed between the noble metal tip **42** and the ground electrode **27**.

The fusion zone **45** is formed so as to satisfy the following configuration. The fusion zone **45** is formed in the entire region between the noble metal tip **42** and the center electrode **5**, so that the entire one end surface of the noble metal tip **42** is joined to the center electrode **5**. Also, as shown in FIG. **20**, the fusion zone **45** includes a first fusion zone **451** and second fusion zones **452**.

The first fusion zone **451** is formed by continuously radiating the laser beam or the electron beam to the boundary region between the center electrode **5** and the one end surface of the noble metal tip **42**, along the circumferential direction of the noble metal tip **42**. Also, the first fusion zone **451** is formed along the entire circumference of the noble metal tip **42** and assumes the form of a disk extending substantially along the other end surface **42**F of the noble metal tip **42**.

Additionally, the second fusion zones **452** are formed by radiating the laser beam or the like in such a manner as to intersect with (in the present embodiment, to be orthogonal to) the first fusion zone **451**, from the side from which the laser beam or the like has been radiated in forming the first fusion zone **451**. In the present embodiment, a plurality of the second fusion zones **452** are provided, and as shown in FIG. **21** (the arrows in FIGS. **21** to **28** indicate the direction of radiation of the laser beam or the like), as viewed from the side toward the other end surface **42**F of the noble metal tip **42**, the second fusion zones **452** are formed at positions located symmetrically with respect to a center axis CL**3** of the noble metal tip **42** (in the present embodiment, at symmetrical positions with respect to the center axis CL**3**).

No particular limitation is imposed on the number of the second fusion zones **452**. For example, as shown in FIG. **22**, only a single second fusion zone **452** may be provided; alternatively, as shown in FIG. **23**, three or more second fusion zones **452** may be provided. Also, no particular limitation is imposed on the positions where the second fusion zones **452** are provided. For example, as shown in FIG. **24**, when the outer circumferential surface of the fusion zone **45** is equally divided along its circumferential direction into two segmental regions, the second fusion zones **452** may be present in only one of the two segmental regions. Also, as shown in FIG. **25**, when the outer circumferential surface of the fusion zone **45** is equally divided along its circumferential direction into three segmental regions, the second fusion zone **452** may be present in each of the three segmental regions. Furthermore, as shown in FIGS. **26** to **28**, when the second fusion zones **452** and the noble metal tip **42** are viewed from the side toward the other end surface **42**F of the noble metal tip **42**, the second fusion zones **452** may be formed at symmetrical positions with respect to the center axis CL**3** of the noble metal tip **42**. Notably, the second fusion zones **452** are not necessarily formed at strictly symmetrical positions with respect to the center axis CL**3** of the noble metal tip **42**, but may be formed at positions slightly deviated from the symmetrical positions.

Also, as shown in FIG. **29**, the second fusion zones **452** may be formed in such a manner as to obliquely intersect with the first fusion zone **451**.

Furthermore, as shown in FIG. **30**, the second fusion zone **452** may be formed in such a manner that its outer surface waves, by continuously (wavily) radiating the laser beam or the like.

The second embodiment yields actions and effects similar to those yielded by the above-described first embodiment with respect to the relation between the center electrode **5** and the noble metal tip **42** to be joined to the center electrode **5**. That is, separation resistance can be greatly improved for the noble metal tip **42** joined to the center electrode **5**.

Third Embodiment

Next, the third embodiment will be described, centering on points of difference from the first embodiment described above. In the first embodiment described above, the fusion zone **35** includes the first fusion zone **351** and the second fusion zones **352**, which intersect with the first fusion zone **351**. However, in the third embodiment, as shown in FIG. **31**, a fusion zone **55** is formed in the form of a plurality of segmental fusion zones **552** which extend along a center axis CL**4** of a noble metal tip **52** in such a manner as to cross the boundary between the ground electrode **27** and one end surface of the noble metal tip **52**. That is, the fusion zone **55** is composed of only the equivalents of the second fusion zones **352** in the first embodiment described above. The fusion zone **55** is formed by intermittently radiating a laser beam or an electron beam a plurality of times from the side toward the distal end surface **27**F of the ground electrode **27** in such a manner as to intersect with a boundary BA**1** between the noble metal tip **52** and the ground electrode **27**.

Also, in the third embodiment, as viewed from the side (in the present embodiment, the side toward the distal end surface **27**F of the ground electrode **27**) from which the laser beam or the electron beam has been radiated, a portion of the outer surface of the fusion zone **55** located on the boundary BA**1** between the noble metal tip **52** and the ground electrode **27** has a length (L**41**+L**42**+L**43**+L**44**+L**45**) which is 30% or more (more preferably 50% or more, far more preferably 70% or more) of the length L**3** of the boundary BA**1**.

In actuality, a portion of the boundary BA**1** between the noble metal tip **52** and the ground electrode **27** does not externally appear in association with formation of the fusion zone **55**; however, the above expression "the boundary BA**1** between the noble metal tip **52** and the ground electrode **27**" means the boundary between the noble metal tip **52** and the ground electrode **27** on the assumption that the fusion zone **55** does not exist. Therefore, "the externally appearing boundary BA**1** between the noble metal tip **52** and the ground electrode **27**" means the boundary between the noble metal tip **52** and the ground electrode **27** which externally appears on the assumption that the fusion zone **55** does not exist. In the third embodiment, the boundary BA**1** is a single line consisting of boundary segments which actually, externally appear, and imaginary line segments (the dotted line segments in FIG. **31**) each of which connects the adjacent boundary segments.

Additionally, in the third embodiment, as shown in FIG. **32**, as viewed from the side toward the other end surface **52**F of the noble metal tip **52**, the segmental fusion zones **552** are formed at positions located symmetrically with respect to a straight line KL**3** which extends along the longitudinal direction of the ground electrode **27** and passes through the center axis CL**4** of the noble metal tip **52**.

Notably, as shown in FIG. **33**, a fusion zone **56** composed of a plurality of segmental fusion zones **562** may be formed by radiating the laser beam or the like from a side toward one of side surfaces **27S1** and **27S2** of the ground electrode **27** in such a manner as to intersect with the boundary BA**1** between the noble metal tip **52** and the center electrode **5**, without radiating the laser beam or the like from the side toward the distal end surface **27**F of the ground electrode **27**. Also, in this case, as viewed from the side toward the other end surface **52**F of the noble metal tip **52**, the segmental fusion zones **562** may be formed at positions located symmetrically with respect to a straight line KL**4** which extends along a direction orthogonal to the longitudinal direction of the ground electrode **27** and passes through the center axis CL**4** of the noble metal tip **52**. Furthermore, as shown in FIG. **34**, as viewed from the side toward the other end surface **52**F of the noble metal tip **52**, segmental fusion zones **572** may be formed at positions located symmetrically with respect to the center axis CL**4** of the noble metal tip **52** by radiating the laser beam or the like from the sides toward the opposite side surfaces **27S1** and **27S2** of the ground electrode **27**.

Also, as shown in FIG. **35**, through radiation of the laser beam or the like from the side toward each of the distal end surface **27**F and the opposite side surfaces **27S1** and **27S2** of the ground electrode **27**, the segmental fusion zones **582** are formed on the distal end surface **27**F and the opposite side surfaces **27S1** and **27S2** of the ground electrode **27**.

Additionally, as shown in FIG. **36**, a fusion zone **59** may be formed of a plurality of segmental fusion zones **592** which are formed continuously, such that an externally exposed portion of the fusion zone **59** waves by wavily radiating the laser beam or the like to the boundary BA**1** between the noble metal tip **52** and the ground electrode **27** instead of intermittently radiating the laser beam or the like.

According to the third embodiment, a plurality of the segmental fusion zones **552** penetrate into both of the ground electrode **27** and the noble metal tip **52**. Therefore, the segmental fusion zones **552** function as, so to speak, wedges, whereby there can be restrained movement of the noble metal tip **52** in relation to the ground electrode **27** associated with a stress difference which arises between the noble metal tip **52** and the ground electrode **27**. As a result, strength of joining the noble metal tip **52** can be improved, whereby excellent separation resistance can be implemented.

Furthermore, as viewed from the side toward the other end surface **52**F of the noble metal tip **52**, the segmental fusion zones **552** are formed at symmetrical positions with respect to the straight line KL**3**. That is, the segmental fusion zones **552** are disposed in a well balanced manner on the boundary surface between the noble metal tip **52** and the ground electrode **27**. Therefore, the segmental fusion zones **552** more effectively exhibit the wedge function, whereby separation resistance can be further enhanced.

Also, as viewed from the side from which the laser beam or the like has been radiated, a portion of the outer surface of the fusion zone **55** located on the boundary BA**1** between the noble metal tip **52** and the ground electrode **27** has a length (L**41**+L**42**+L**43**+L**44**+L**45**) which is 30% or more of a length L**3** of the boundary BA**1**. That is, the segmental fusion zones **552** are formed over a relatively wide range of a boundary region between a perimetrical portion of the noble metal tip **52** and the ground electrode **27**, the boundary region being where a particularly large stress difference arises. Therefore, the segmental fusion zones **552** can more effectively exhibit the wedge function, whereby separation resistance can be more improved.

Fourth Embodiment

Next, the fourth embodiment will be described, centering on points of difference from the third embodiment described above. In the third embodiment described above, the noble metal tip **52** is joined to the ground electrode **27** via the fusion zone **55**; however, in the fourth embodiment, as shown in FIG. **37**, a noble metal tip **62** is joined to a forward end portion of the center electrode **5** via a fusion zone **65**. That is, in the third embodiment, the object member is the ground electrode **27**, whereas, in the fourth embodiment, the object member is the center electrode **5**.

The fusion zone **65** is formed in the form of a plurality of segmental fusion zones **652** which extend along a center axis CL**5** of the noble metal tip **62** in such a manner as to cross a boundary BA**2** between the center electrode **5** and one end surface of the noble metal tip **62**. The fusion zone **65** is formed by intermittently radiating a laser beam or an electron beam a plurality of times from a side toward the outer circumference of the center electrode **5** in such a manner as to intersect with the boundary BA**2** between the noble metal tip **62** and the center electrode **5**.

Furthermore, as shown in FIGS. **38** and **39** (FIG. **38** is a sectional view taken along line J-J of FIG. **37** with only the segmental fusion zones **652** being hatched, and FIG. **39** is a development view of outer circumferential surfaces of the center electrode **5**, the noble metal tip **62**, etc. of FIG. **37**), the total length of outer surfaces of those portions X**1** (portions represented by bold lines in FIGS. **38** and **39**) of the segmental fusion zones **65** which are located on the boundary BA**2** between the noble metal tip **62** and the center electrode **5** (i.e., the length of a portion of the fusion zone **65** located on the boundary BA**2**) is 30% or more (more preferably, 50% or more) of a length L**5** of the boundary BA**2**.

As shown in FIG. **40**, a fusion zone **66** may be formed of a plurality of segmental fusion zones **662** which are formed continuously, by wavily radiating the laser beam or the like to the boundary BA**2** between the noble metal tip **62** and the center electrode **5** instead of intermittently radiating the laser beam or the like. Also, in this case, as shown in FIGS. **41** and **42** (FIG. **41** is a sectional view taken along line J-J of FIG. **40** with only the segmental fusion zones **662** being hatched, and FIG. **42** is a development view of outer circumferential surfaces of the center electrode **5**, the noble metal tip **62**, etc. of FIG. **40**), the total length of outer surfaces of those portions X**2** (portions represented by bold lines in FIGS. **41** and **42**) of the fusion zone **66** which are located on the boundary BA**2** between the noble metal tip **62** and the center electrode **5** is 30% or more (more preferably, 50% or more, far more preferably 70% or more) of a length L**6** of the boundary BA**2**.

Furthermore, as shown in FIGS. **43**(*a*) and **43**(*b*), a fusion zone **67** may be formed such that segmental fusion zones **672** are disposed at reduced intervals as measured on the boundary BA**2** along the circumferential direction of the noble metal tip **62**.

Also, as shown in FIG. **44**(*a*) [the dotted line in FIG. **44**(*a*) indicates the path of movement of the position of radiation of the laser beam or the like], a fusion zone **68** may be formed such that adjacent segmental fusion zones **682** overlap each other at least on the boundary BA**2**. In this case, since the segmental fusion zones **682** narrow in a radially inward direction, as viewed on a section of the tip **62** taken in parallel with the center axis CL**5**, the fusion zone **68** located radially inward (located toward the center axis CL**5** of the tip **62**) assumes a wavy form as shown in FIG. **44**(*b*); thus, it can be confirmed that the laser beam or the like has been wavily radiated.

According to the fourth embodiment, by virtue of the segmental fusion zones **652**, there can be restrained movement of the noble metal tip **62** in relation to the center electrode **5** associated with a stress difference which arises between the noble metal tip **62** and the center electrode **5**. As a result, strength of joining the noble metal tip **62** can be improved, whereby excellent separation resistance can be implemented.

Also, a portion of the outer surface of the fusion zone **65** located on the boundary BA**2** has a length which is 30% or more of a length L**6** of the boundary BA**2**. That is, the segmental fusion zones **652** are formed over a relatively wide range of a boundary region between a circumferential portion of the noble metal tip **62** and the center electrode **5**, the boundary region being where a particularly large stress difference arises. Therefore, the segmental fusion zones **652** can more effectively exhibit the wedge function, whereby separation resistance can be more improved.

Furthermore, in the case where the segmental fusion zones **672** are disposed at reduced intervals as measured on the boundary BA**2**, the fusion zone **67** can effectively absorb a stress difference between the noble metal tip **62** and the center electrode **5** associated with thermal expansion, whereby separation resistance can be far more greatly improved.

Next, in order to verify actions and effects to be yielded by the above embodiments, there were manufactured spark plug samples 1 to 7 serving as examples, and a spark plug sample 8 serving as a comparative example, 30 pieces each, in which the noble metal tips were welded to the respective ground electrodes by use of a fiber laser beam having a spot diameter of 0.03 mm. The samples were subjected to a separation-resistance evaluation test. The separation-resistance evaluation test is briefly described below. The test conducted 1,000 cycles of heating/cooling on the samples in the atmosphere, each cycle consisting of heating by a burner for two minutes such that the noble metal tips had a temperature of 1,100° C., and subsequent cooling such that the noble metal tips were maintained at 200° C. for one minute. After completion of 1,000 test cycles, a portion of one end surface of each of the noble metal tips which was separated from the corresponding ground electrode was measured in area; there was counted the number of those samples in which the area of the separated portion was 50% or less of the area of the one end surface of the noble metal tip (quantity of nondefectives); and the percentage of the quantity of nondefectives to 30 pieces (percentage of nondefectives) was calculated. In the samples, the ground electrodes were formed from INCONEL (registered trademark) **600**, and the noble metal tips were formed from an Ir-10Pt alloy. The employed noble metal tips had a square parallelepiped shape such that their one end surfaces measured 1.6 mm×1.6 mm before welding (i.e., the employed noble metal tips had a relatively large cross-sectional area), so as to generate a relatively large stress difference between the noble metal tips and the ground electrodes in association with thermal expansion.

Furthermore, the samples 1 to 8 were configured as follows. The sample 1 was configured as follows: the fiber laser beam is radiated from the side toward the distal end surface of the ground electrode (the same also applies to the samples 2 to 5), and, assuming that the fusion zone is equally divided into three segmental regions along the width direction of the noble metal tip, the first fusion zone and the second fusion zone are in contact with each other only in one of the opposite end ones of the three segmental regions (i.e., configured similar to FIG. **6**). The sample 2 was configured such that the first fusion zone and the second fusion zone were in contact with each other only in the center one of the three segmental regions (i.e., configured similar to FIG. **8**). The sample 3 was configured such that the first fusion zone and the second fusion zone were in contact with each other in the opposite end ones of the three segmental regions (i.e., configured similar to FIG. **9**). The sample 4 was configured such that the first fusion zone and the second fusion zone were in contact with each other in each of the three segmental regions (i.e., configured similar to FIG. **7**). The sample 5 was configured such that, while the first fusion zone and the second fusion zone were in contact with each other in the three segmental regions, the number of the second fusion zones was increased to five (i.e., configured similar to FIG. **3**). Furthermore, the sample 6 was configured such that, in order to form the fusion zone, in addition to radiation of the fiber laser beam from the side toward the distal end surface of the ground electrode, the fiber laser beam was radiated from a side toward one of the side surfaces of the ground electrode (i.e., configured similar to FIG. **12**). The sample 7 was configured such that, in order to form the fusion zone, the fiber laser beam was radiated from the sides toward the opposite side surfaces of the ground electrode (i.e., configured similar to FIG. **11**). Notably, the samples 6 and 7 were configured such that, as viewed from the side from which the fiber laser beam had been radiated, the first fusion zone and the second fusion zones were formed similar to those of the sample 5. The sample 8 according to the comparative example was configured such that only the first fusion zone was formed by radiating the fiber laser beam from the side toward the distal end surface of the ground electrode, without provision of the second fusion zone.

Table 1 shows the results of the above-mentioned test.

TABLE 1

	Percentage of nondefectives (%)	Quantity of nondefectives
Sample 1	43	13
Sample 2	53	16
Sample 3	60	18
Sample 4	73	22
Sample 5	87	26
Sample 6	97	29
Sample 7	100	30
Sample 8	7	2

As is apparent from Table 1, as compared with the sample 8 serving as a comparative example, the samples 1 to 7 serving as examples have superior separation resistance. Conceivably, this is for the following reason or the like: by virtue of provision of the second fusion zone, a relatively large stress difference which arose between the noble metal tip and the ground electrode and was difficult for the first fusion zone to absorb alone was able to be sufficiently absorbed.

Also, the following was found out: the sample in which the first fusion zone and the second fusion zone are in contact with each other in the center one of the three segmental regions (sample 2) has more superior separation resistance, and the sample in which the first fusion zone and the second fusion zone are in contact with each other in the opposite end ones of the three segmental regions (sample 3) has far more superior separation resistance. Conceivably, this is for the following reason or the like: by virtue of provision of the second fusion zone in the central segmental region or the opposite end segmental regions, a stress difference which the first fusion zone failed to absorb was able to be effectively absorbed.

Additionally, the following was confirmed: the samples in which the first fusion zone and the second fusion zone are in contact with each other in each of the three segmental regions (samples 4 and 5), and the samples in which the fusion zone is formed by radiating the fiber laser beam from the sides toward at least two of the distal end surface and the opposite side surfaces of the ground electrode (samples 6 and 7), have quite superior separation resistance.

From the above-mentioned test results, in order to improve separation resistance, preferably, the fusion zone is composed of the first fusion zone and the second fusion zone(s), which intersects with the first fusion zone.

Also, in view of further improvement of separation resistance, more preferably, the first fusion zone and the second fusion zone are in contact with each other in the center one or the opposite end ones of the three segmental regions, and, far more preferably, the first fusion zone and the second fusion zone are in contact with each other in each of the three segmental regions.

Furthermore, in view of far more improvement of separation resistance, desirably, the fusion zone is formed by radiating the laser beam or the like from the sides toward at least two of the distal end surface and the opposite side surfaces of the ground electrode.

Next, there were manufactured spark plug samples 11 to 15 serving as examples, and a spark plug sample 16 serving as a comparative example, 30 pieces each, in which the noble metal tips were welded to the respective center electrodes by use of a fiber laser beam having a spot diameter of 0.03 mm. The samples were subjected to the above-mentioned separation-resistance evaluation test. In this test, one cycle consisted of heating by a burner for two minutes such that the noble metal tips had a temperature of 1,000° C., and subsequent cooling such that the noble metal tips were maintained at 200° C. for one minute. The center electrodes were formed from INCONEL 600, and the employed noble metal tips were formed from an Ir-5Rh alloy and had a circular columnar shape having an outside diameter of 1.0 mm.

The samples 11 to 16 were configured as follows. In each of the samples 11 to 16, while the center electrode and the noble metal tip were rotated about the axis, the fiber laser beam was radiated to a boundary region therebetween, thereby forming the first fusion zone along the entire circumference of the noble metal tip. Additionally, in the sample 11, only a single second fusion zone intersecting with the first fusion zone was provided (i.e., configured similar to FIG. **22**). In the sample 12, two second fusion zones intersecting with the first fusion zone were provided (i.e., configured similar to FIG. **24**). In the sample 13, the second fusion zones were provided at symmetrical positions with respect to the center axis of the noble metal tip (i.e., configured similar to FIG. **21**). Additionally, in the sample 14, three second fusion zones were provided (i.e., configured similar to FIG. **23**). The sample 15 was configured as follows: when the second fusion zones and the noble metal tip are viewed from the side toward the other end surface of the noble metal tip, the second fusion zones are located at symmetrical positions with respect to the center axis of the noble metal tip, and, assuming that the outer circumferential surface of the fusion zone is equally divided along its circumferential direction into three segmental regions, the second fusion zone is present in each of the three segmental regions (i.e., configured similar to FIG. **26**). Also, in the sample 16 serving as a comparative example, only the first fusion zone was formed without provision of the second fusion zone.

Table 2 shows the results of the above-mentioned test.

TABLE 2

	Percentage of nondefectives (%)	Quantity of nondefectives
Sample 11	50	15
Sample 12	53	16
Sample 13	80	24

TABLE 2-continued

	Percentage of nondefectives (%)	Quantity of nondefectives
Sample 14	83	25
Sample 15	97	29
Sample 16	20	6

As is apparent from Table 2, as compared with the sample 16 serving as a comparative example, the samples 11 to 15 serving as examples have superior separation resistance.

Also, it was confirmed that provision of a plurality of the second fusion zones further improved separation resistance. In this connection, the following was found out: the sample in which the second fusion zones are provided symmetrically with respect to the center axis of the noble metal tip (sample 13), and the sample in which the second fusion zone is present in each of the three segmental regions (sample 15), are far more superior in separation resistance to the samples in which the same number of the second fusion zones are provided (samples 12 and 14). Conceivably, this is for the following reason: since the second fusion zones were provided at symmetrical positions or the like with respect to the center axis of the noble metal tip, a stress difference was evenly applied to thick portions of the fusion zone (portions where the second fusion zones are present); as a result, the stress difference was able to be more effectively absorbed.

From the above-mentioned test results, similar to the case of joining the noble metal tip to the ground electrode, also in the case of joining the noble metal tip to the center electrode, in order to improve separation resistance of the noble metal tip, preferably, the fusion zone is composed of the first fusion zone and the second fusion zone(s), which intersects with the first fusion zone.

Also, in order to further improve separation resistance, more preferably, as viewed from the side toward the other end surface of the noble metal tip, the second fusion zones are formed at symmetrical positions with respect to the center axis of the noble metal tip, or in such a manner as to be present in the respective ones of the three segmental regions.

Next, in order to verify actions and effects to be yielded by the above third and fourth embodiments, there were manufactured spark plug samples 21 to 25 serving as examples, and a spark plug sample 26 serving as a comparative example, 20 pieces each, in which the noble metal tips were welded to the respective center electrodes by use of a fiber laser beam. The samples were subjected to 1,000 cycles of a heating and cooling test, each cycle consisting of heating by a burner for two minutes such that the noble metal tips had a temperature of 1,000° C., and subsequent cooling such that the noble metal tips were maintained at 200° C. for one minute. Subsequently, the samples were subjected to impact which was applied for one hour by use of a JIS-type impact test machine. Then, the samples were checked to see if the noble metal tip was detached from the center electrode, thereby obtaining the number of samples free from detachment of the noble metal tip (tip-detachment-free quantity) with respect to the samples 21 to 25 and the sample 26. In this test, the center electrodes were formed from INCONEL 600, and the employed noble metal tips were formed from an Ir-10Pt alloy and had a circular columnar shape having an outside diameter of 1.0 mm and a height of 0.7 mm. Furthermore, test conditions other than test time (such as amplitude of vibration and the free length of a spring) conformed to the specifications of the impact resistance test described in JIS B8031.

The samples 21 to 25 serving as examples have a plurality of segmental fusion zones which cross the boundary between the center electrode and one end surface of the noble metal tip, and were configured as follows. The sample 21 was configured as follows: a plurality of the segmental fusion zones which extend along the direction of the center axis of the noble metal tip are provided by intermittently radiating the fiber laser beam from the side toward the outer circumference of the center electrode (i.e., configured similar to FIG. **37**), and the total length of outer surfaces of those portions of the fusion zone which are located on the boundary between the noble metal tip and the center electrode is 30% of the length of the boundary. The sample 22 was configured as follows: the configuration is similar to that of FIG. **37**, and the total length of outer surfaces of those portions of the fusion zone which are located on the boundary is 50% of the length of the boundary. The sample 23 was configured as follows: an externally exposed portion of the fusion zone waves by wavily radiating the fiber laser beam from the side toward the outer circumference of the center electrode (i.e., configured similar to FIG. **40**), and the total length of outer surfaces of those portions of the fusion zone which are located on the boundary is 30% of the length of the boundary. The sample 24 was configured as follows: the configuration is similar to that of FIG. **40**, and the total length of outer surfaces of those portions of the fusion zone which are located on the boundary is 50% of the length of the boundary. The sample 25 was configured as follows: the equivalent of the first fusion zone is provided by radiating the fiber laser beam to the boundary, and an externally exposed portion of the fusion zone waves by wavily radiating the fiber laser beam in such a manner as to intersect with the equivalent of the first fusion zone (in other words, in such a manner as to cross the boundary between the center electrode and the noble metal tip) (i.e., configured similar to FIG. **30**).

Meanwhile, the sample 26 serving as a comparative example was configured as follows: only the equivalent of the first fusion zone is provided by radiating the fiber laser beam along the boundary between the center electrode and the noble metal tip.

Table 3 shows the results of the above-mentioned test.

TABLE 3

	Tip-detachment-free quantity
Sample 21	12
Sample 22	17
Sample 23	13
Sample 24	18
Sample 25	18
Sample 26	4

As is apparent from Table 3, the samples having a plurality of segmental fusion zones which cross the boundary between the center electrode and the noble metal tip (samples 21 to 25) exhibit a tip-detachment-free quantity in excess of 10, indicating that the samples have good separation resistance. Conceivably, this is for the following reason: since a plurality of the segmental fusion zones penetrate into both of the center electrode and the noble metal tip, the segmental fusion zones function as, so to speak, wedges, whereby there is restrained movement of the noble metal tip in relation to the center electrode.

Also, the following was confirmed: particularly, the samples in which the total length of outer surfaces of those portions of the fusion zone which are located on the boundary between the noble metal tip and the center electrode is 50% or more of the length of the boundary (samples 22 and 24) have quite superior separation resistance equivalent to that of the sample having the equivalent of the first fusion zone, in addition to the fusion zone (sample 25).

From the above-mentioned test results, in order to improve separation resistance, preferably, the fusion zone includes a plurality of segmental fusion zones which cross the boundary between the center electrode and one end surface of the noble metal tip.

Also, in order to reliably exhibit the effect of improving separation resistance, preferably, the length of outer surfaces of those portions of the fusion zone which are located on the boundary between the noble metal tip and the center electrode is 30% or more of the length of the boundary. Also, in view of further improvement of separation resistance, more preferably, the length of outer surfaces of those portions of the fusion zone which are located on the boundary between the noble metal tip and the center electrode is 50% or more of the length of the boundary.

The above-mentioned test was conducted on the samples in which the noble metal tip was joined to the center electrode. However, it is conceived that, even when a similar test is conducted on spark plug samples in which the noble metal tip is joined to the ground electrode, similar results will be yielded.

The present invention is not limited to the above-described embodiments, but may be embodied, for example, as follows. Of course, applications and modifications other than those exemplified below are also possible.

(a) In the embodiments described above, the noble metal tip **32** (**42**, **52**, **62**) is joined to one of the ground electrode **27** and the center electrode **5** via the fusion zone **35** (**45**, **55**, **65**). However, as shown in FIG. **45**, noble metal tips **72** and **82** may be joined to the ground electrode **27** and the center electrode **5** via fusion zones **75** and **85**, respectively, the fusion zones **75** and **85** having configurations similar to those of the above embodiments. In this case, superior separation resistance can be implemented for both of the noble metal tips **72** and **82**.

(b) In the first embodiment described above, when the noble metal tip **32** and the fusion zone **35** are viewed from the side from which the laser beam or the like has been radiated to the surface of the ground electrode **27**, the first fusion zone **351** is formed along the entire width of the noble metal tip **32**. However, as shown in FIG. **46**, the first fusion zone **351** may be formed such that its width is smaller than that of the noble metal tip **32**. Also, instead of the first fusion zone **351** being continuously formed, as shown in FIG. **47**, the first fusion zone **351** may be formed intermittently along the perimetrical direction (width direction) of the noble metal tip **32**.

(c) In the first embodiment described above, the entire one end surface of the noble metal tip **32** is joined to the ground electrode **27**. However, as shown in FIG. **48**, a fusion zone **95** may be formed such that a portion of the one end surface of the noble metal tip **32** is joined to the ground electrode **27**. Also, in the second embodiment described above, the entire one end surface of the noble metal tip **42** is joined to the center electrode **5**; however, a portion of the one end surface of the noble metal tip **42** may be joined to the center electrode **5**. However, in order to maintain sufficient joining strength, preferably, half or more of the one end surface of the noble metal tip **32** (**42**) is joined to the ground electrode **27** (the center electrode **5**).

(d) In the first embodiment described above, the length of outer surfaces of the second fusion zones **352** along the perimetrical direction of the noble metal tip **32** is 30% or more of the length of the outer surface of the first fusion zone **351** along the perimetrical direction of the noble metal tip **32**. However, in view of further improvement of separation resistance, the length of outer surfaces of the second fusion zones **352** is more preferably 50% or more, far more preferably 70% or more, of the length of the outer surface of the first fusion zone **351**.

Also, in the second embodiment described above, the length of outer surfaces of the second fusion zones **452** along the circumferential direction of the noble metal tip **42** is not particularly specified. However, in order to further improve separation resistance, desirably, the length is 30% or more (more preferably 50% or more, far more preferably 70% or more) of the length of the outer surface of the first fusion zone **451** along the circumferential direction of the noble metal tip **42**.

(e) In the first and third embodiments described above, the noble metal tip **32** (**52**) is joined to the inner side surface **27**I of the ground electrode **27**. However, as shown in FIG. **49**, a noble metal tip **102** may be joined to the distal end surface **27**F of the ground electrode **27** via a fusion zone **105**.

(f) In the first embodiment described above, the first fusion zone **351** has a maximum thickness T_{MAX} of 0.3 mm or less. However, the first fusion zone **351** may have a maximum thickness T_{MAX} of 0.3 mm or more.

(g) In the embodiments described above, the tool engagement portion **19** has a hexagonal cross section. However, the shape of the tool engagement portion **19** is not limited thereto. For example, the tool engagement portion **19** may have a Bi-HEX (modified dodecagonal) shape [IS022977:2005(E)] or the like.

DESCRIPTION OF REFERENCE NUMERALS

1: spark plug
2: ceramic insulator (insulator)
3: metallic shell
5: center electrode
27: ground electrode
27F: distal end surface (of ground electrode)
27I: inner side surface (of ground electrode)
27S**1**, **27**S**2**: side surface (of ground electrode)
32, **42**, **52**, **62**: noble metal tip
32F, **42**F: other end surface (of noble metal tip)
35, **45**, **55**, **65**: fusion zone
351, **451**: first fusion zone
352, **452**: second fusion zone
552, **652**: segmental fusion zone
CL**1**: axis
CL**2**, CL**3**, CL**4**, CL**5**: center axis (of noble metal tip)

The invention claimed is:

1. A spark plug comprising:

a rod like center electrode extending in a direction of an axis;

a tubular insulator provided around the center electrode;

a tubular metallic shell provided around the insulator;

a ground electrode whose proximal end is welded to the metallic shell and whose distal end faces the center electrode; and

a columnar noble metal tip formed from a noble metal alloy and provided on at least one object member of the center electrode and the ground electrode;

one end surface of the noble metal tip being joined to the object member via a fusion zone formed through radiation of a laser beam or an electron beam from a side toward a side surface of the noble metal tip;

the spark plug being characterized in that the fusion zone comprises:

a first fusion zone formed through radiation of the laser beam or the electron beam along the entire circumference of a boundary between the object member and the one end surface of the noble metal tip along a perimetrical direction of the noble metal tip, and

a second fusion zone formed through radiation of the laser beam or the electron beam from the side from which the laser beam or the electron beam has been radiated in forming the first fusion zone, and intersecting with the first fusion zone; wherein

the thickness of the second fusion zone along a longitudinal center axis of the noble metal tip is greater than the thickness of the first fusion zone along the longitudinal center axis of the noble metal tip.

2. The spark plug according to claim **1**, wherein the noble metal tip is joined to at least an inner side surface of the ground electrode, and the fusion zone is formed through radiation of the laser beam or the electron beam from a side toward at least one of a distal end surface and opposite side surfaces of the ground electrode, and

when the noble metal tip and the fusion zone are viewed from the side from which the laser beam or the electron beam has been radiated to the surface of the ground electrode,

assuming that a portion of the fusion zone located between the ground electrode and the noble metal tip is equally divided into three segmental regions along a width direction of the noble metal tip, the first fusion zone and the second fusion zone are in contact with each other in at least a center one of the three segmental regions.

3. The spark plug according to claim **1**, wherein

the noble metal tip is joined to at least the ground electrode, and the fusion zone is formed through radiation of the laser beam or the electron beam from a side toward at least one of a distal end surface and opposite side surfaces of the ground electrode, and

when the noble metal tip and the fusion zone are viewed from the side from which the laser beam or the electron beam has been radiated to the surface of the ground electrode,

assuming that a portion of the fusion zone located between the ground electrode and the noble metal tip is equally divided into three segmental regions along a width direction of the noble metal tip, the first fusion zone and the second fusion zone are in contact with each other in at least opposite end ones of the three segmental regions.

4. The spark plug according to claim **1**, wherein

the noble metal tip is joined to at least the ground electrode, and

through radiation of the laser beam or the electron beam from a side toward each of a distal end surface and opposite side surfaces of the ground electrode, the second fusion zone is formed on each of the distal end surface and the opposite side surfaces of the ground electrode.

5. The spark plug according to claim **1**, wherein

the noble metal tip is joined to at least the ground electrode;

a plurality of the second fusion zones are formed; and

as viewed from a side toward the other end surface of the noble metal tip, the second fusion zones are formed at positions located symmetrically with respect to a center axis of the noble metal tip.

6. The spark plug according to claim **1**, wherein

the noble metal tip is joined to at least the ground electrode;

a plurality of the second fusion zones are formed; and

as viewed from a side toward the other end surface of the noble metal tip, the second fusion zones are formed at positions located symmetrically with respect to a straight line which extends along a longitudinal direction of the ground electrode and passes through a center axis of the noble metal tip.

7. The spark plug according to claim **1**, wherein

the noble metal tip is joined to at least the ground electrode;

a plurality of the second fusion zones are formed; and

as viewed from a side toward the other end surface of the noble metal tip, the second fusion zones are formed at positions located symmetrically with respect to a straight line which extends along a direction orthogonal to a longitudinal direction of the ground electrode and passes through a center axis of the noble metal tip.

8. The spark plug according to claim **1**, wherein

the noble metal tip is joined to at least the center electrode;

the first fusion zone is formed along the entire circumference of the noble metal tip;

a plurality of the second fusion zones are formed; and

as viewed from a side toward the other end surface of the noble metal tip, the second fusion zones are formed at positions located symmetrically with respect to a center axis of the noble metal tip.

9. The spark plug according to claim **1**, wherein the first fusion zone has a maximum thickness of 0.3 mm or less along a center axis of the noble metal tip.

10. The spark plug according to claim **1**, wherein a length of an outer surface of the second fusion zone along a perimetrical direction of the noble metal tip is 30% or more of a length of an outer surface of the first fusion zone along the perimetrical direction of the noble metal tip.

11. The spark plug according to claim **1**, wherein a length of an outer surface of the second fusion zone along a perimetrical direction of the noble metal tip is 50% or more of a length of an outer surface of the first fusion zone along the perimetrical direction of the noble metal tip.

12. The spark plug according to claim **1**, wherein a length of an outer surface of the second fusion zone along a perimetrical direction of the noble metal tip is 70% or more of a length of an outer surface of the first fusion zone along the perimetrical direction of the noble metal tip.

13. The spark plug according to claim **1**, wherein

as viewed on a plane of projection which is orthogonal to a center axis of the noble metal tip and on which the noble metal tip and the fusion zone are projected along the center axis,

a projected overlap region of the noble metal tip and the fusion zone accounts for 50% or more of a projected region of the noble metal tip.

14. The spark plug according to claim **8**, wherein assuming that an outer circumferential surface of the fusion zone is equally divided into three segmental regions along a circumferential direction thereof, the second fusion zone exists in each of the three segmental regions.

15. A spark plug comprising:

a rod like center electrode extending in a direction of an axis;

a tubular insulator provided around the center electrode;

a tubular metallic shell provided around the insulator;

a ground electrode whose proximal end is welded to the metallic shell and whose distal end faces the center electrode; and

a columnar noble metal tip formed from a noble metal alloy and provided on at least one object member of the center electrode and the ground electrode;

the spark plug being characterized in that:

one end surface of the noble metal tip is joined to the object member via a fusion zone which, as viewed along the axial direction from the side from which the laser beam or the electron beam has been radiated, has a wave shape formed by radiating a laser beam or an electron beam from a side toward a side surface of the noble metal tip in such a manner as to intersect with a boundary between the noble metal tip and the object member,

wherein the wave shape has opposing crests formed on opposite sides of the boundary between the noble metal tip and the object member,

the wave shape is substantially sinusoidal, and

the fusion zone comprises a plurality of segmental fusion zones formed across the boundary between the object member and the one end surface of the noble metal tip.

16. The spark plug according to claim **15**, wherein the noble metal tip is joined to at least an inner side surface of the ground electrode, and the fusion zone is formed through radiation of the laser beam or the electron beam from a side toward at least one of a distal end surface and opposite side surfaces of the ground electrode, and

as viewed from the side from which the laser beam or the electron beam has been radiated, a portion of an outer surface of the fusion zone located on a boundary between the noble metal tip and the ground electrode has a length which is 30% or more of a length of the boundary.

17. The spark plug according to claim **15**, wherein the noble metal tip is joined to at least an inner side surface of the ground electrode, and the fusion zone is formed through radiation of the laser beam or the electron beam from a side toward at least one of a distal end surface and opposite side surfaces of the ground electrode, and

as viewed from the side from which the laser beam or the electron beam has been radiated, a portion of an outer surface of the fusion zone located on a boundary between the noble metal tip and the ground electrode has a length which is 50% or more of a length of the boundary.

18. The spark plug according to claim **15**, wherein the noble metal tip is joined to at least the ground electrode, and

through radiation of the laser beam or the electron beam from a side toward each of a distal end surface and opposite side surfaces of the ground electrode, the segmental fusion zones are formed on the distal end surface and the opposite side surfaces of the ground electrode.

19. The spark plug according to claim **15**, wherein

the noble metal tip is joined to at least the ground electrode, and

as viewed from a side toward the other end surface of the noble metal tip, the segmental fusion zones are formed at positions located symmetrically with respect to a center axis of the noble metal tip.

20. The spark plug according to claim **15**, wherein

the noble metal tip is joined to at least the ground electrode, and

as viewed from a side toward the other end surface of the noble metal tip, the segmental fusion zones are formed at positions located symmetrically with respect to a straight line which extends along a longitudinal direction of the ground electrode and passes through a center axis of the noble metal tip.

21. The spark plug according to claim **15**, wherein

the noble metal tip is joined to at least the ground electrode, and

as viewed from a side toward the other end surface of the noble metal tip, the segmental fusion zones are formed at positions located symmetrically with respect to a straight line which extends along a direction orthogonal to a longitudinal direction of the ground electrode and passes through a center axis of the noble metal tip.

22. The spark plug according to claim **15**, wherein

the noble metal tip is joined to at least the center electrode, and

a portion of an outer surface of the fusion zone located on a boundary between the noble metal tip and the center electrode has a length which is 30% or more of a length of the boundary.

23. The spark plug according to claim **15**, wherein

the noble metal tip is joined to at least the center electrode, and

a portion of an outer surface of the fusion zone located on a boundary between the noble metal tip and the center electrode has a length which is 50% or more of a length of the boundary.

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